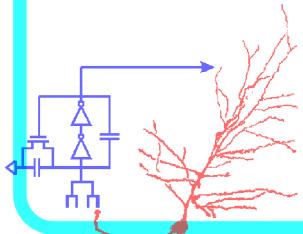


“Foreground and Background at the Cocktail Party”

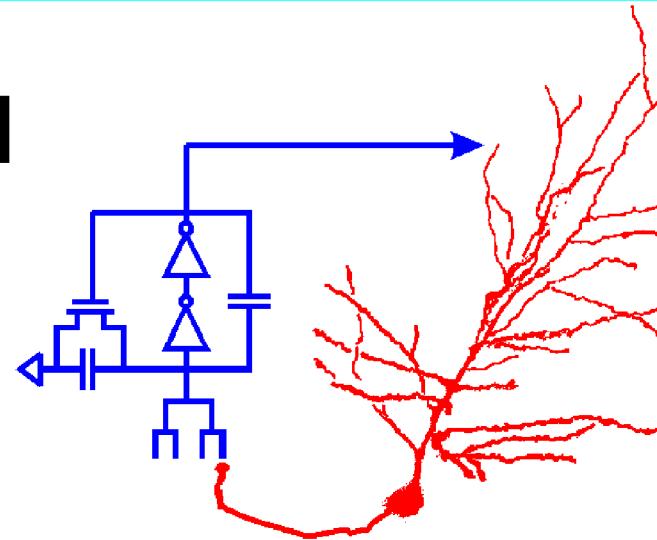
The Role of Auditory Attention in Neural Processing and Behavior

Jonathan Z. Simon

*Biology
Electrical & Computer Engineering
Neuroscience and Cognitive Science
Bioengineering*



Computational Sensorimotor Systems Laboratory



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Supported by

NIH: NIDCD/NIBIB/NIA
1R03DC004382, 1R01EB004750,
1R01AG027573, 1R01DC007657,
1F31NS055589

*Whole Brain
Neurophysiology*

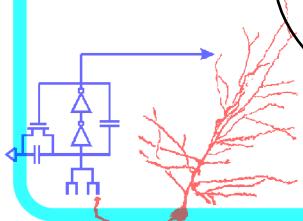
*Computational
Neuroscience*

*Auditory
Cortex*

*Single Neuron
Neurophysiology*

*Neural Signal
Processing*

*Auditory
Brainstem*



Chait et al.,
J Neuroscience 2007

Whole Brain Neurophysiology

Luo et al.,
J Neurophysiology (in press)

Chait et al.,
J Neuroscience 2005

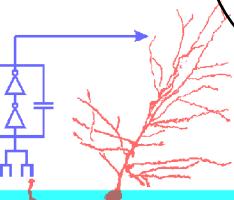
Luo et al.,
J Neurophysiology 2006

Auditory Cortex

Chait et al.,
NeuroReport 2004

Simon & Wang,
J Neuroscience Methods 2005

Wang et al.,
Neural Engineering 2005



Computational Neuroscience

Aytekin et al.,
Neural Computation (in press)

Xiang et al.,
Neural Engineering 2005

Chait et al.,
Cerebral Cortex 2006

Chait et al.,
J Neurophysiology 2007

Chait et al.,
Brain & Language 2007

de Cheveigné & Simon,
J Neuroscience Methods 2007

Grau-Serrat et al.,
Biological Cybernetics 2003

Single Neuron Neurophysiology

Ahmar et al.,
Neural Engineering 2005

Ahmar & Simon,
Neural Engineering 2005

de Cheveigné & Simon,
J Neuroscience Methods (in press)

Auditory Brainstem

Whole Brain Neurophysiology

- Chait et al.,
J Neuroscience 2007
- Chait et al.,
J Neurophysiology 2007
- Luo et al.,
J Neurophysiology 2006
- Chait et al.,
J Neuroscience 2005
- Luo et al.,
J Neurophysiology (in press)

Computational Neuroscience

- Aytekin et al.,
Neural Computation (in press)
- Simon et al.,
Neural Computation 2007

Ahmar et al.,
Neural Engineering 2005

Auditory Computations

Auditory Cortex

- Simon & Wang,
J Neuroscience Methods 2005

Chait et al.,
NeuroReport 2004

Single Neuron Neurophysiology

- Xiang et al.,
Neural Engineering 2005

de Cheveigné & Simon,
J Neuroscience Methods 2007

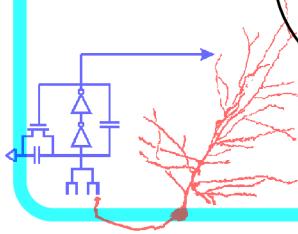
Grau-Serrat et al.,
Biological Cybernetics 2003

Neural Signal Processing

de Cheveigné & Simon,
J Neuroscience Methods (in press)

Ahmar & Simon,
Neural Engineering 2005

Auditory Brainstem

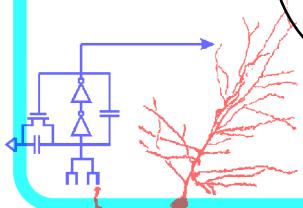


*Whole Brain
Neurophysiology*

*Computational
Neuroscience*

*Auditory
Cortex*

*Neural Signal
Processing*



*Whole Brain
Neurophysiology*

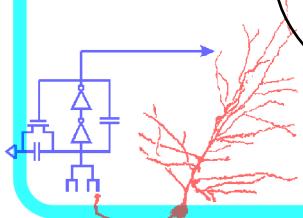
*Computational
Neuroscience*

*Auditory
Cortex*

*The Role of
Auditory Attention
in Neural Processing
and Behavior*

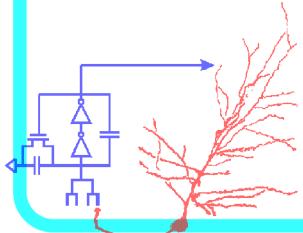
*Neural Signal
Processing*

Juanjuan Xiang
Mounya Elhilali



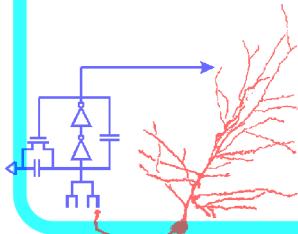
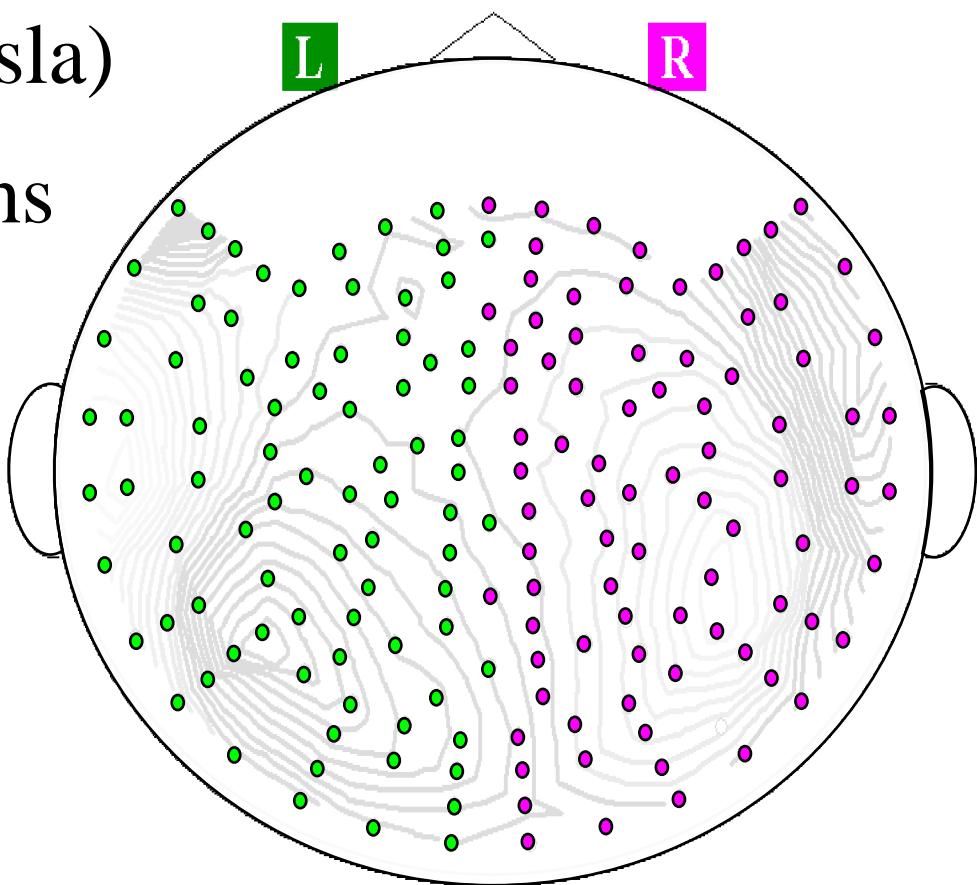
Outline

- Magnetoencephalography (MEG) as a tool of Non-Invasive Auditory Physiology
- MEG in the Frequency Domain
- Neural & Behavioral Correlates of Attention



Magnetoencephalography (MEG)

- Non-invasive, Passive, Silent Neural Recordings
- Simultaneous Whole-Head Recording (~200 sensors)
- Sensitivity
 - high: $\sim 100 \text{ fT}$ (10^{-13} Tesla)
 - low: $\sim 10^4 - \sim 10^6$ neurons
- Temporal Resolution: $\sim 1 \text{ ms}$
- Spatial Resolution
 - coarse: $\sim 1 \text{ cm}$
 - ambiguous



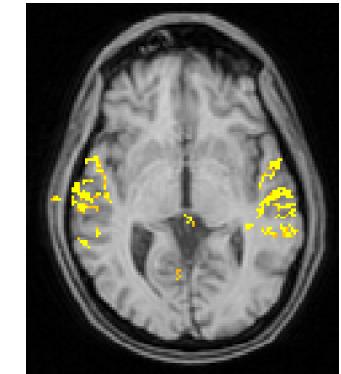
Functional Imaging

Non-invasive recording
from human brain
(Functional brain imaging)

Hemodynamic
techniques

Functional magnetic
resonance imaging
fMRI

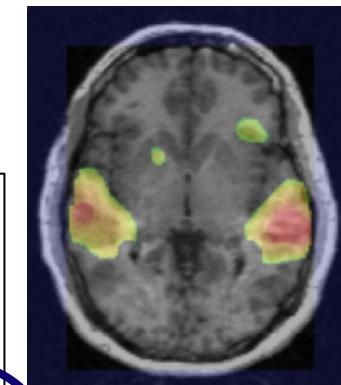
Excellent spatial resolution
(~ 1-2 mm)
Poor temporal resolution
(~ 1 s)



Positron emission
tomography
PET

PET, EEG require
across-subject
averaging

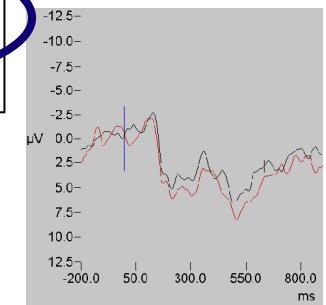
fMRI and MEG can
capture effects in
single subjects



Electroencephalography
EEG

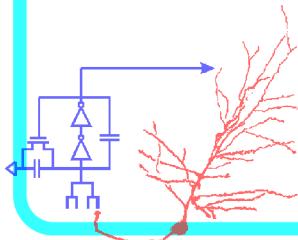
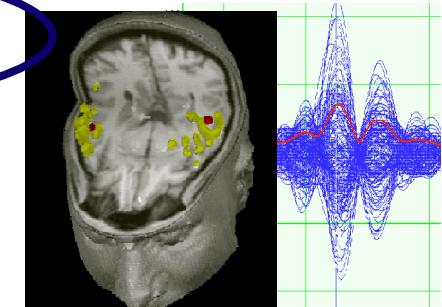
Poor spatial resolution
(~ 1 cm)

Excellent temporal resolution
(~ 1 ms)



Electromagnetic
techniques

Magnetoencephalography
MEG



Primary Neural Current

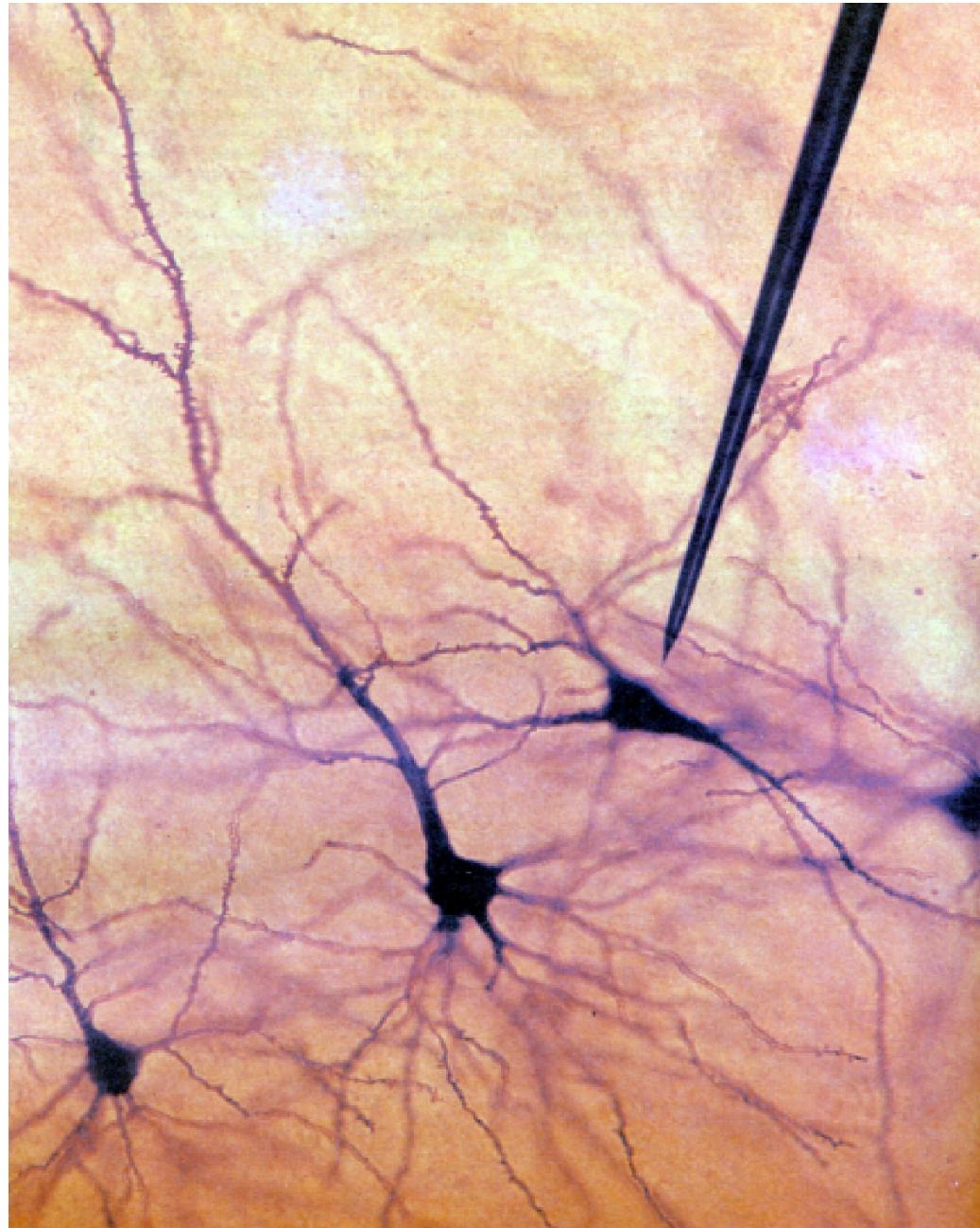
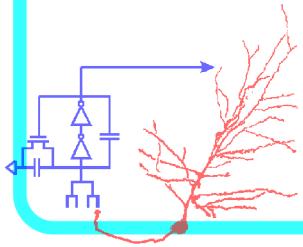


Photo by Fritz Goro



Primary Neural Current

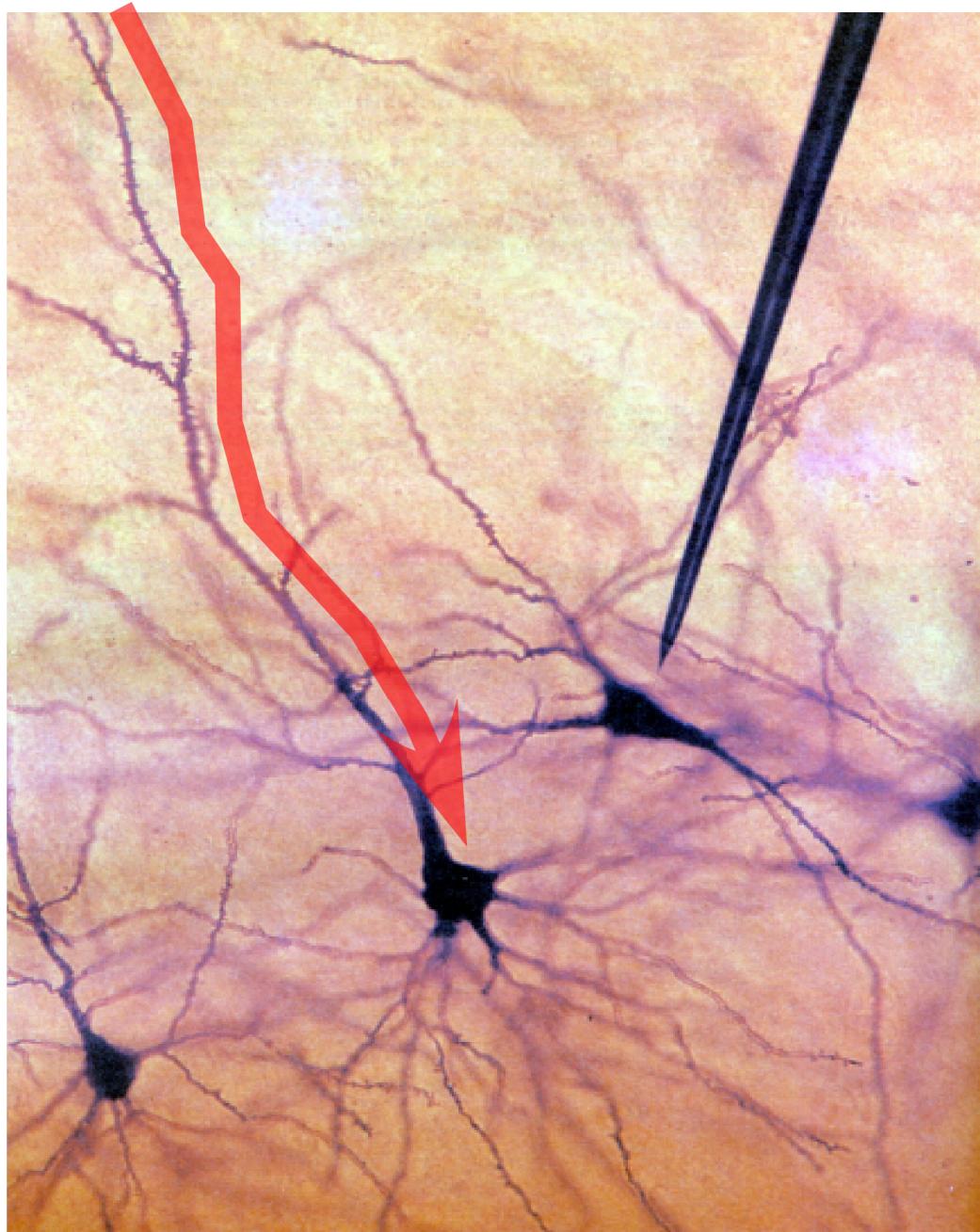
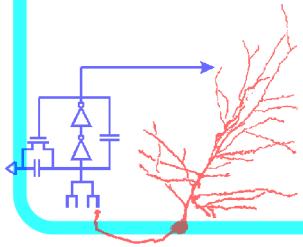
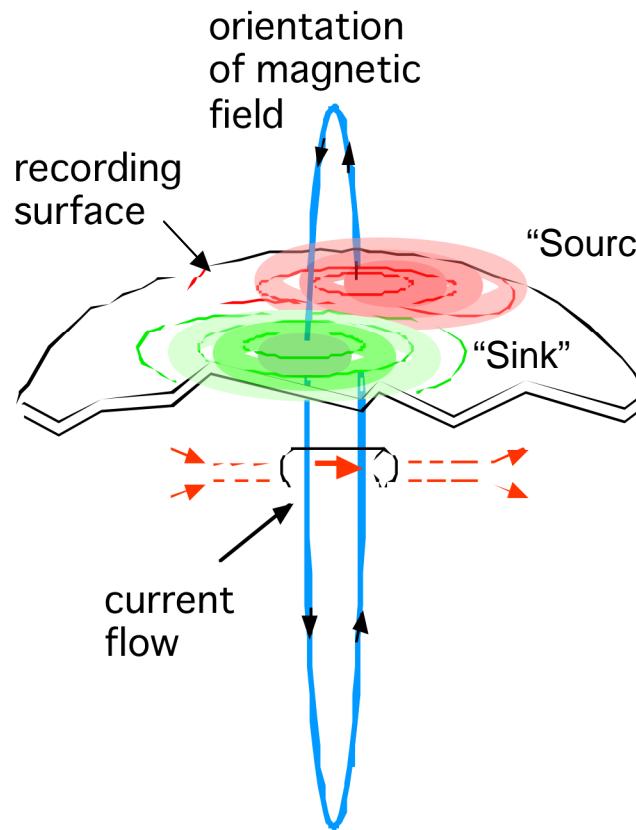
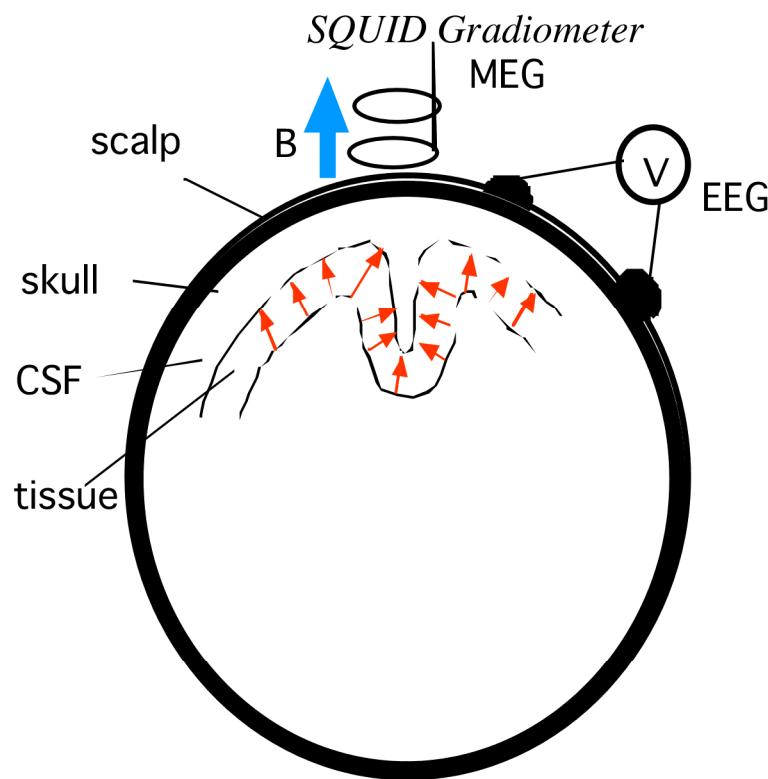


Photo by Fritz Goro

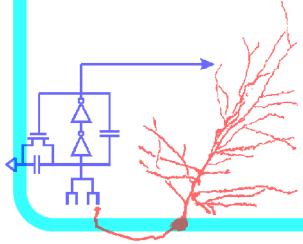


MEG Measures Neural Currents



Magnetic
Dipolar
Field
(Projection)

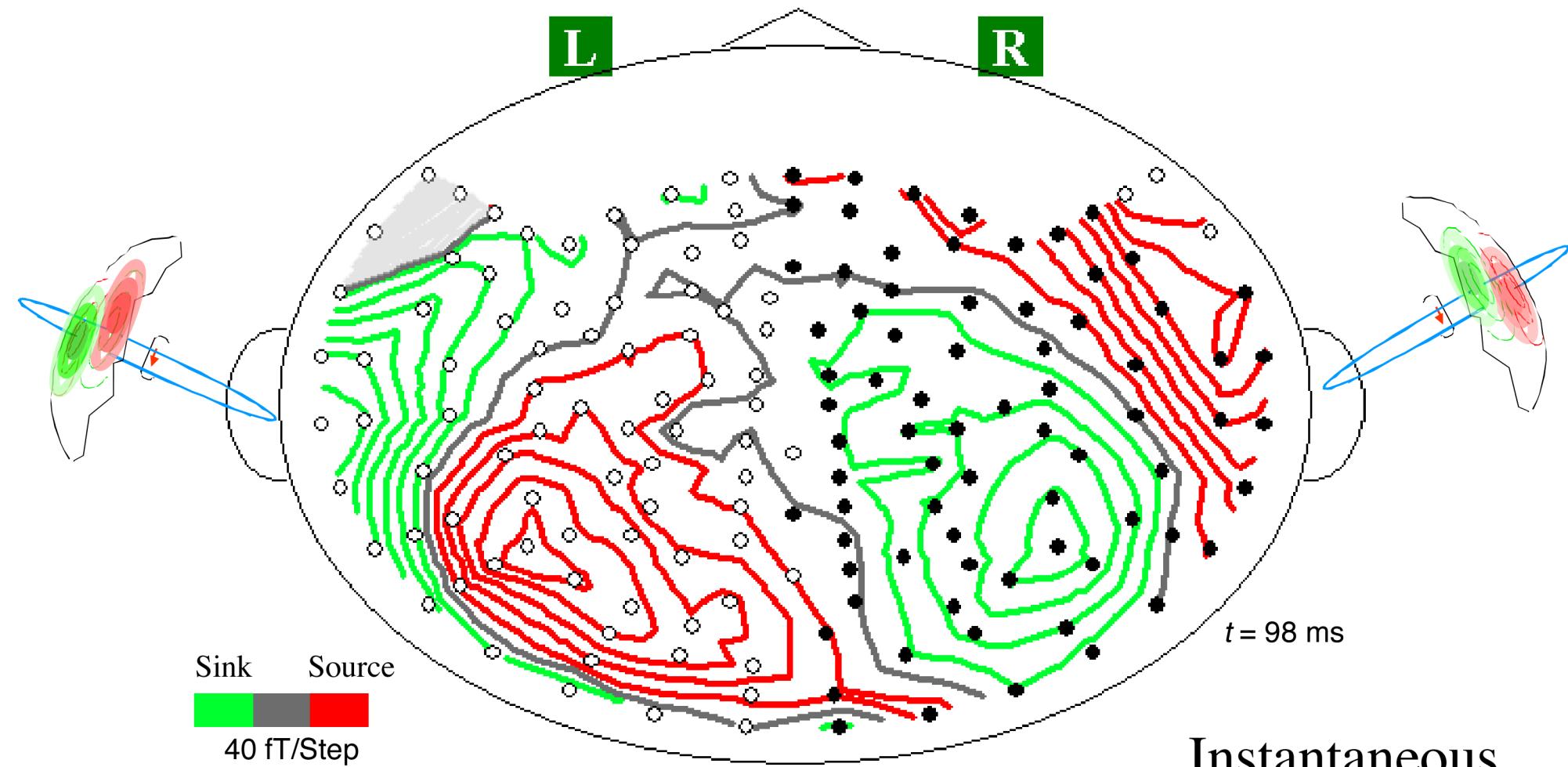
- Direct electrophysiological measurement
 - not hemodynamic
 - real-time
- No unique solution for distributed source



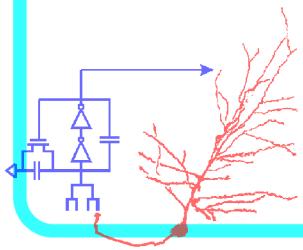


MEG Response

Flattened Isofield Contour Map

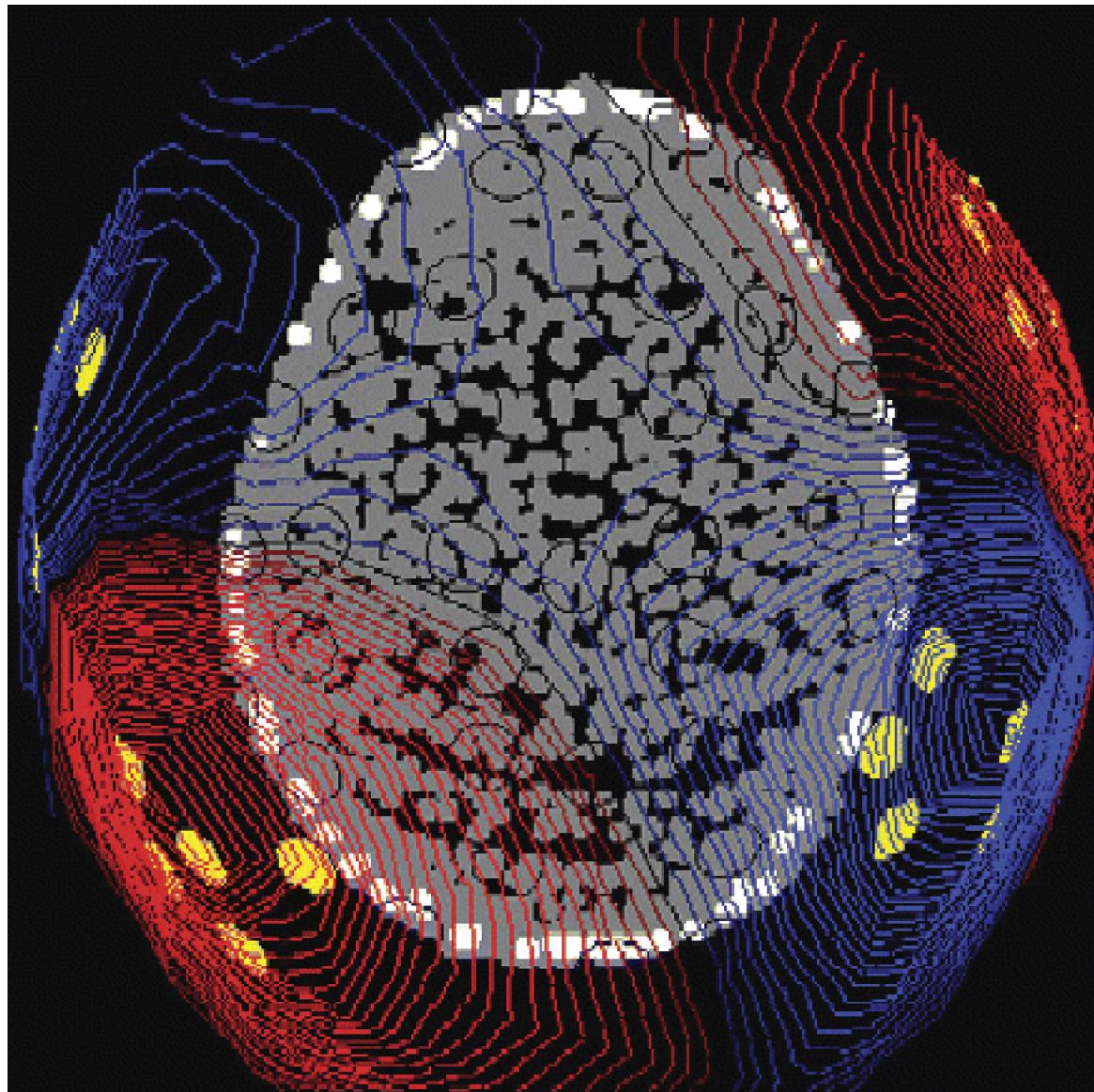


Instantaneous
Magnetic
Field

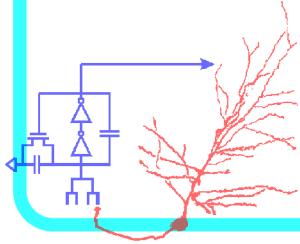


MEG Response

3-D Isofield Contour Map

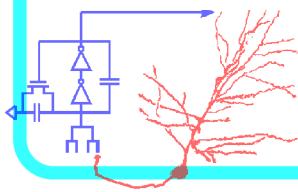
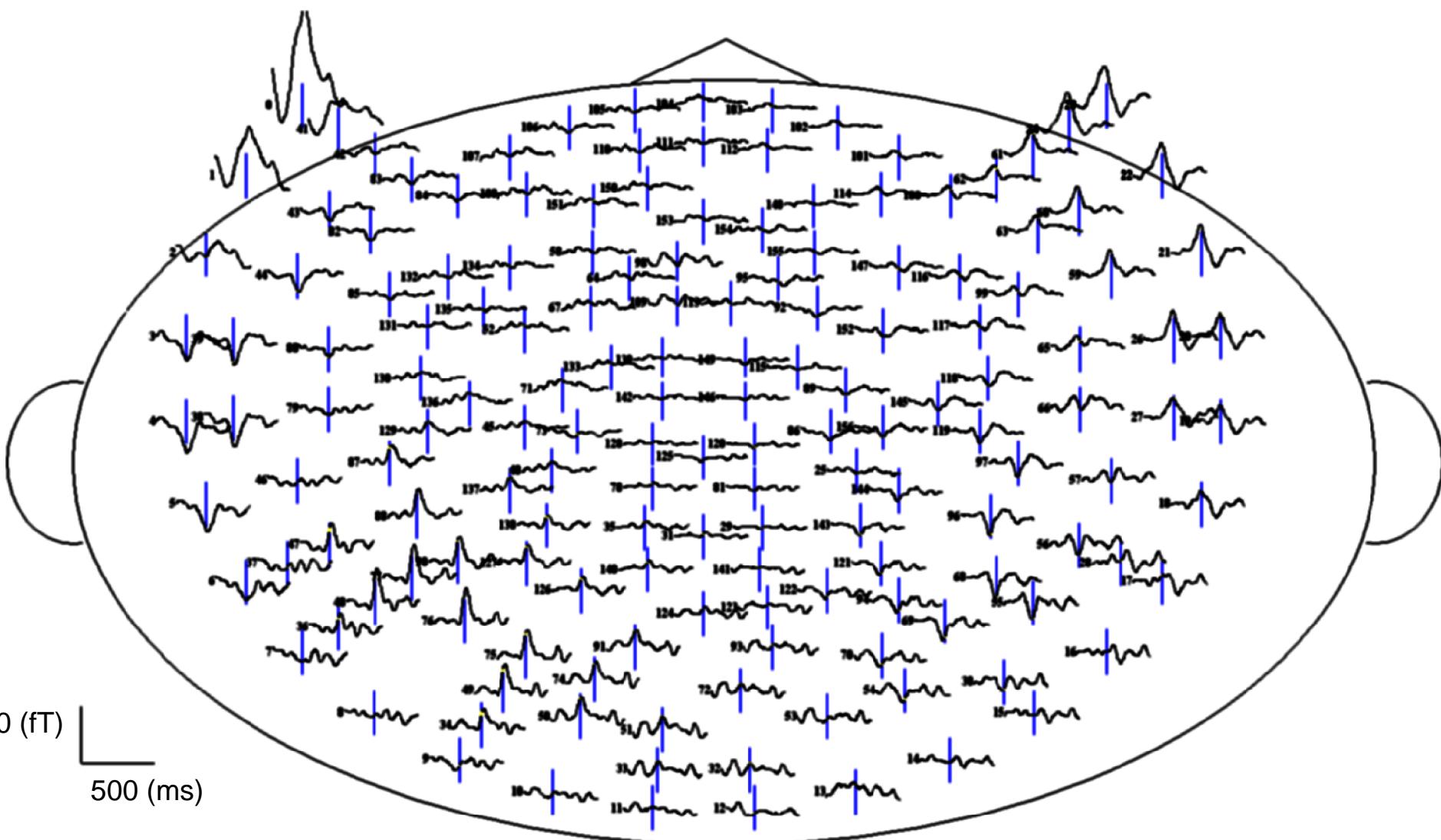


Chait et al.,
Cerebral Cortex 2006



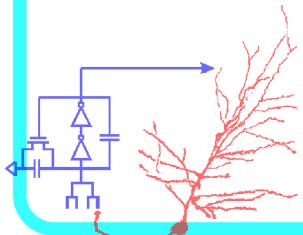
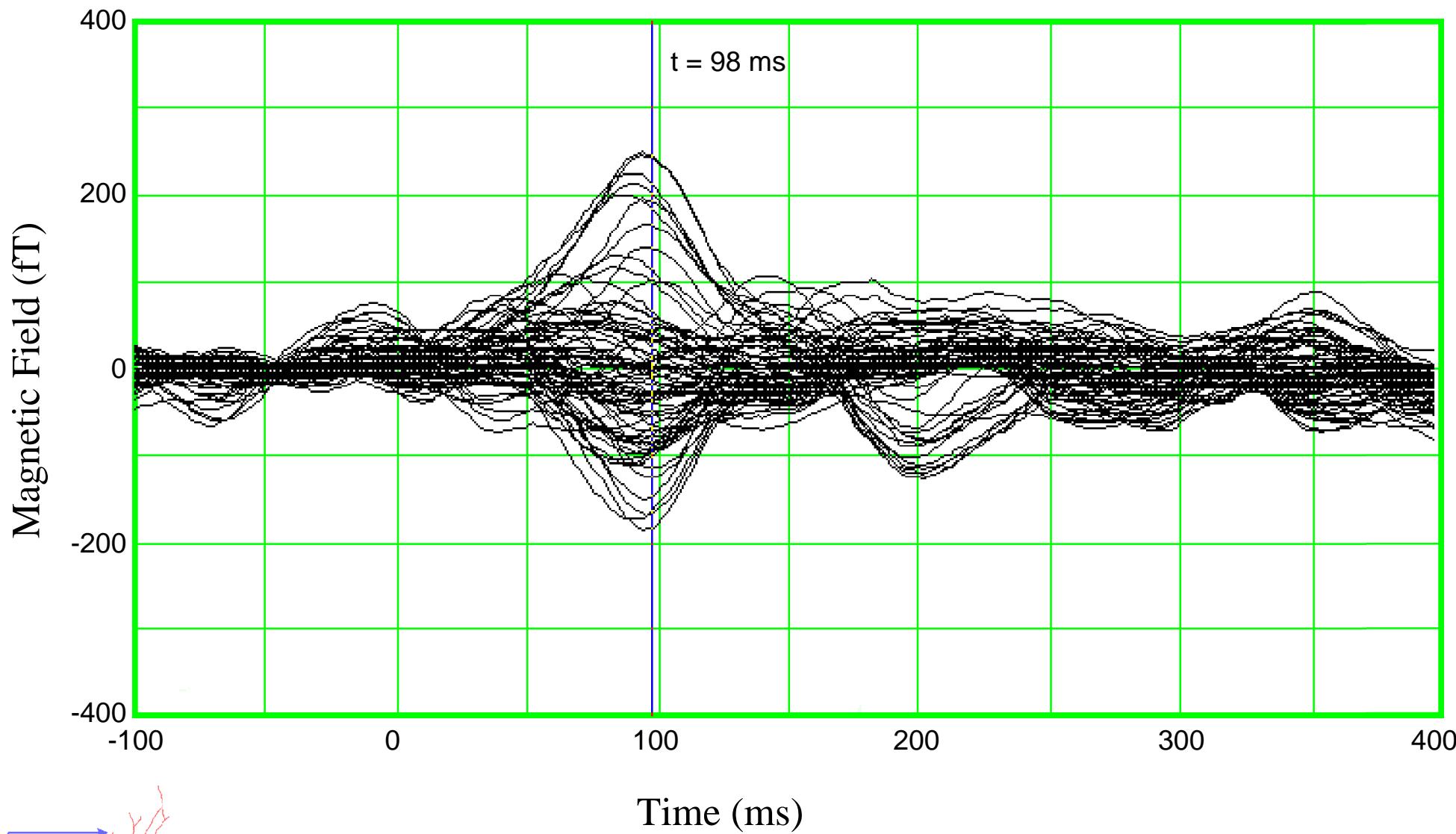
MEG Response

Spatial Map of Time Series



MEG Response

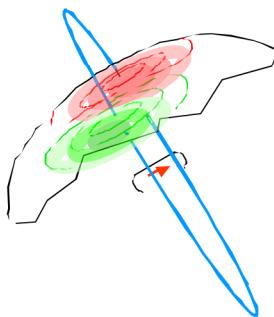
Butterfly Plot



Time Course of MEG Responses

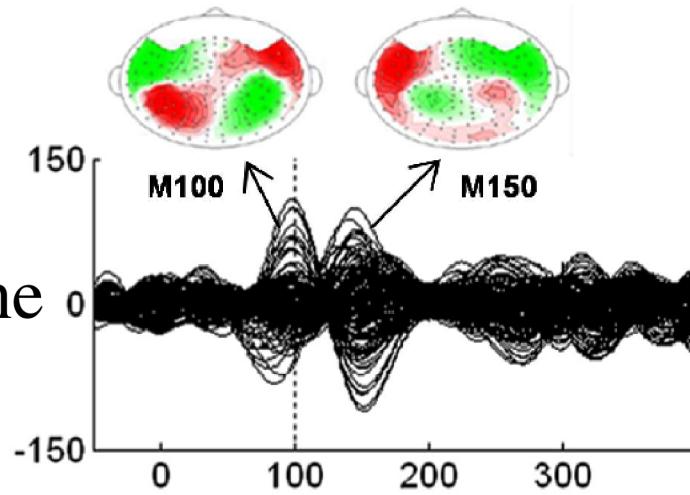
Evoked Responses

MEG Events Time-Locked
to Stimulus Event

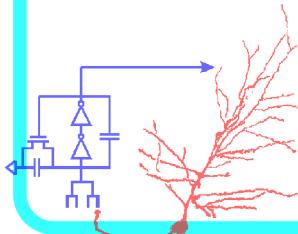
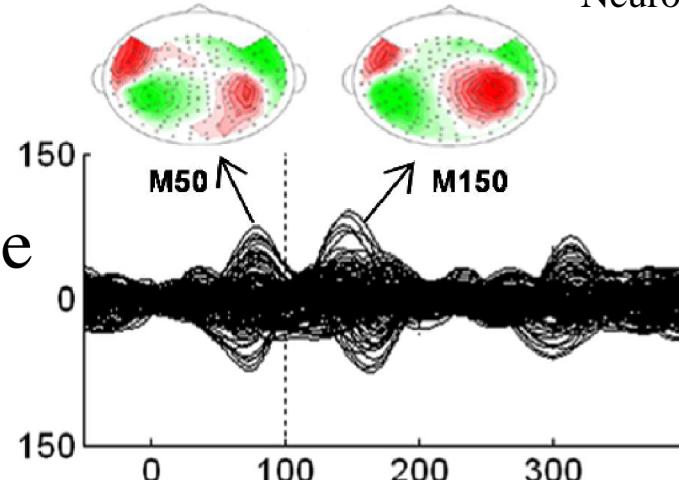


Broadband Noise

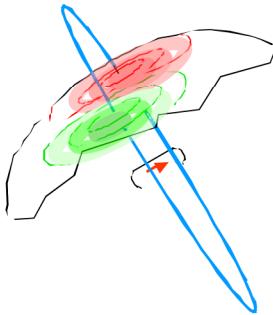
Pure Tone



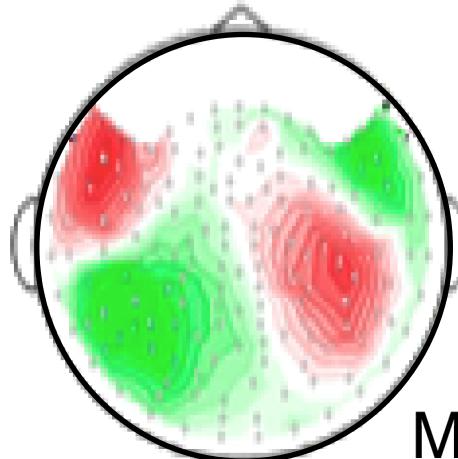
Chait et al.,
NeuroReport 2004



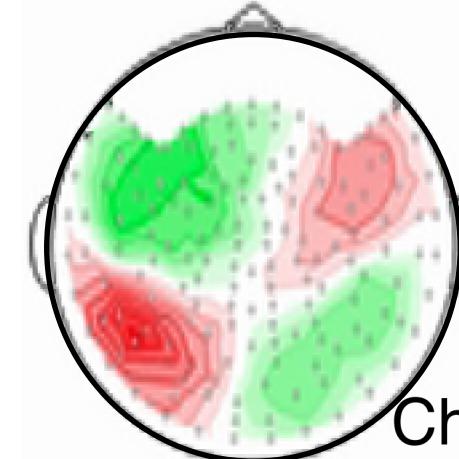
Spatial Auditory MEG Responses



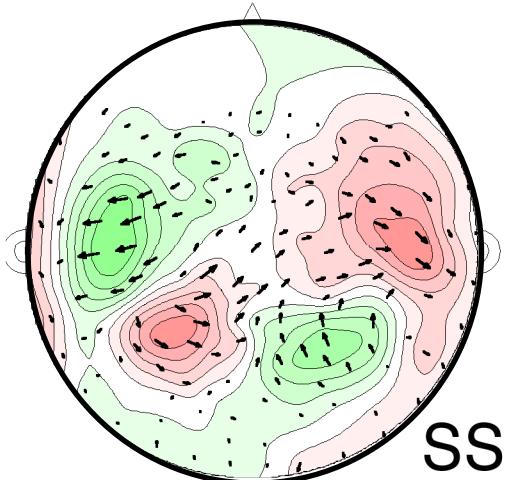
Auditory Responses
Robust
Strongly Lateralized



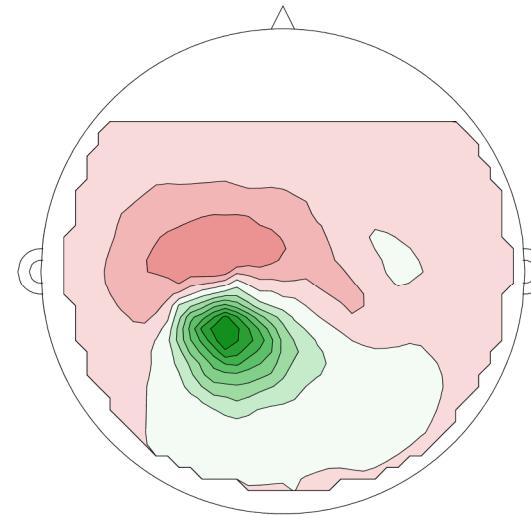
Chait et al.,
NeuroReport 2004



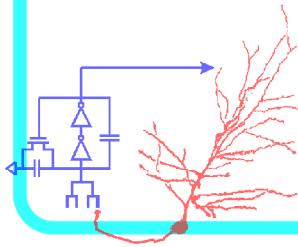
Chait et al.,
J. Neuroscience 2007



Simon & Wang
J. Neuroscience Methods 2005

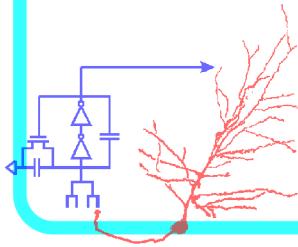


Xiang et al.,
Neural Engineering 2005



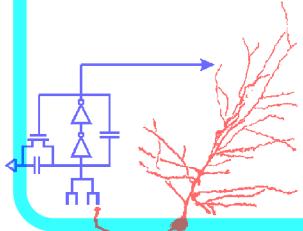
MEG as Auditory Physiology Tool

- Advantages of humans over animals
 - Subjects can be rented (by the hour)
 - Subjects can be trained in minutes
 - Better grasp of subjects' perceptual space (?)
 - Access to Speech & Language processing (?)
- Advantage of Whole Head Recording
- Disadvantage of Neural Source Localization
 - Coarseness/Ambiguity in Source Location
 - Blindness to Many Kinds of Coding
- Neutral Aspects
 - Neural Source is Dendritic Current (not Spikes)
 - Humans not typical mammals (?)
 - New Technique/Immature Analysis Tools



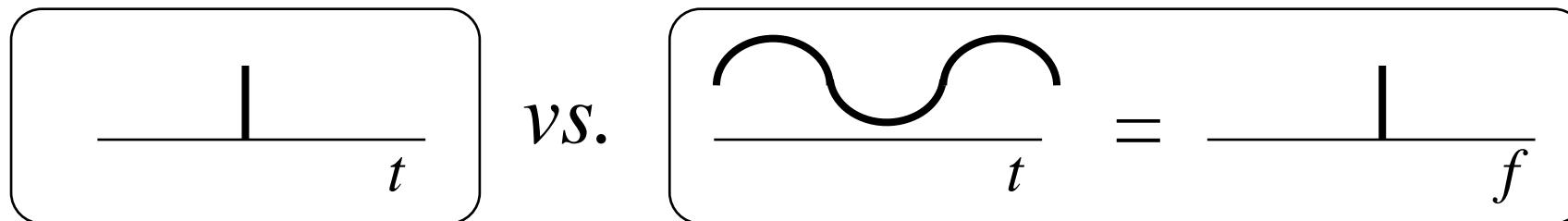
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- Magnetoencephalography (MEG) as a tool of Non-Invasive Auditory Physiology
- MEG in the Frequency Domain
- Neural & Behavioral Correlates of Attention

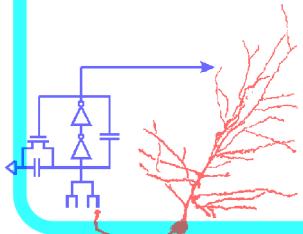


An Alternative to Time: Frequency

- Use Stimuli localized in Frequency, not time

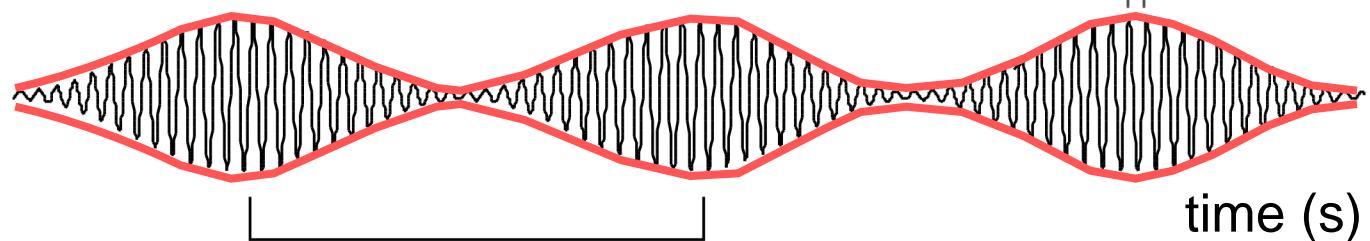


- Examine Response at Same Frequency
- Steady State Response (SSR)
- Frequency Response/Transfer Function

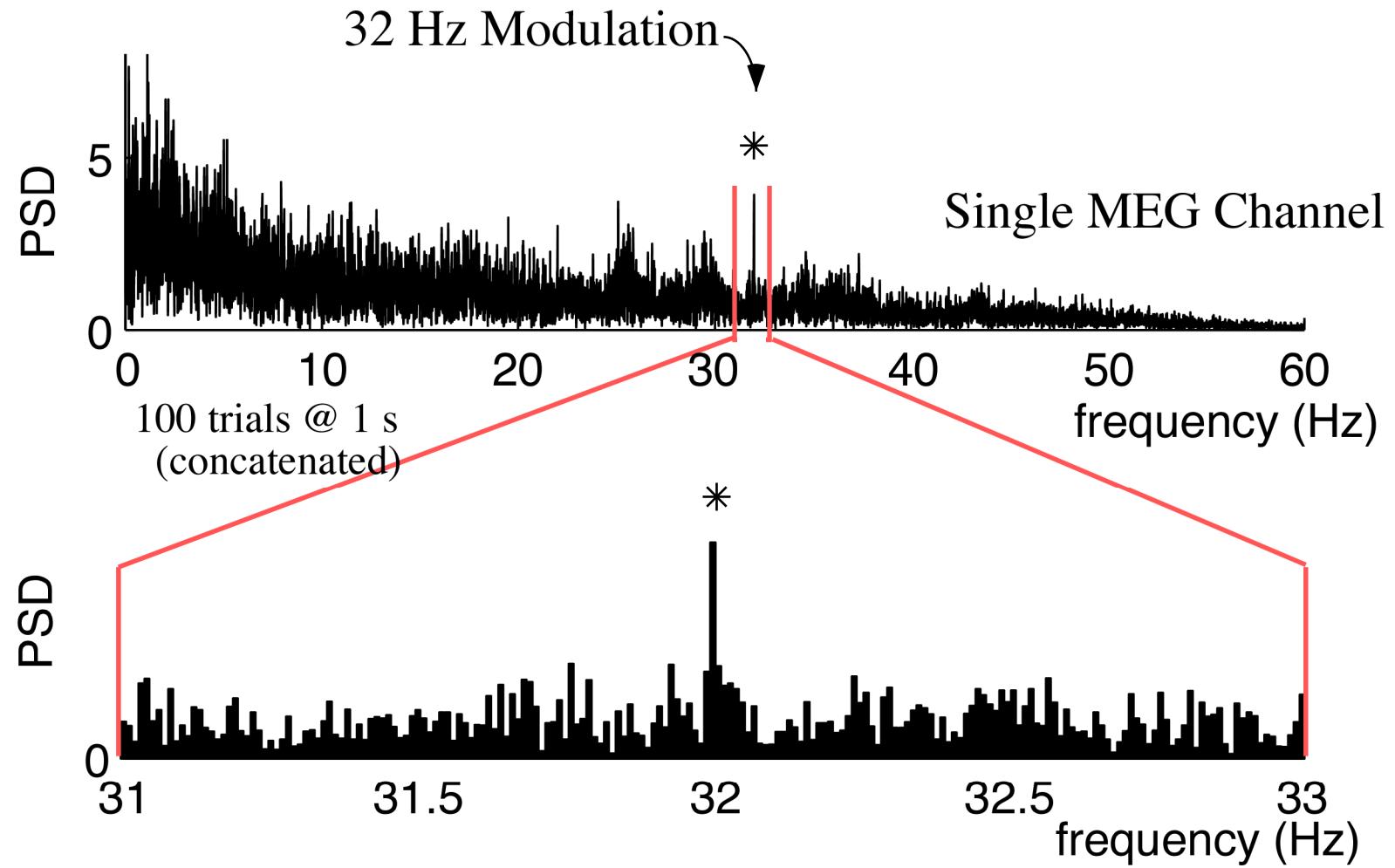


Frequency Response

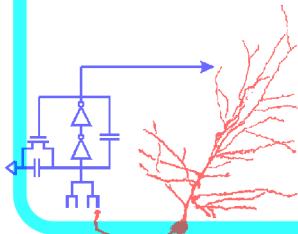
Stimulus



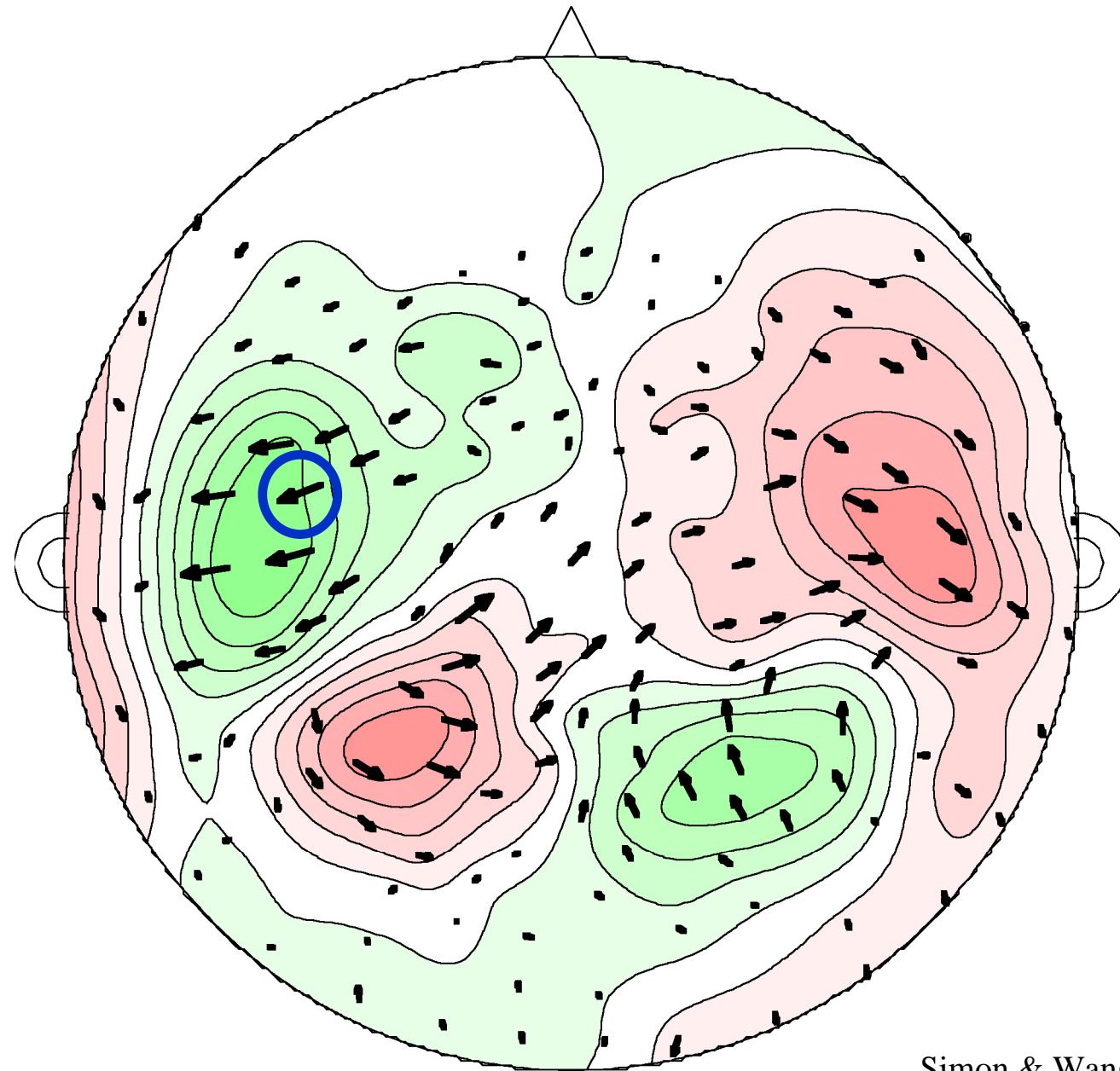
Response



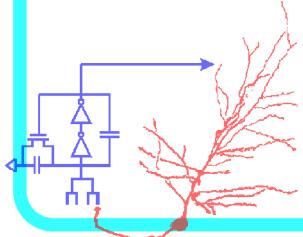
Precise Phase-Locking: 0.01 Hz
Little trial-to-trial jitter



Whole Head Steady State Response



32 Hz

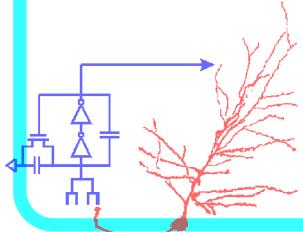


Simon & Wang
J. Neuroscience Methods 2005

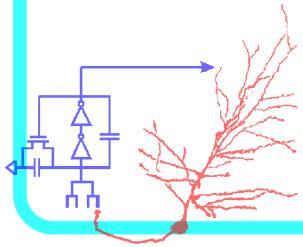
Computational Sensorimotor Systems Laboratory

Outline

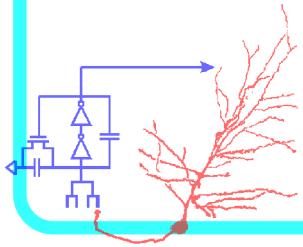
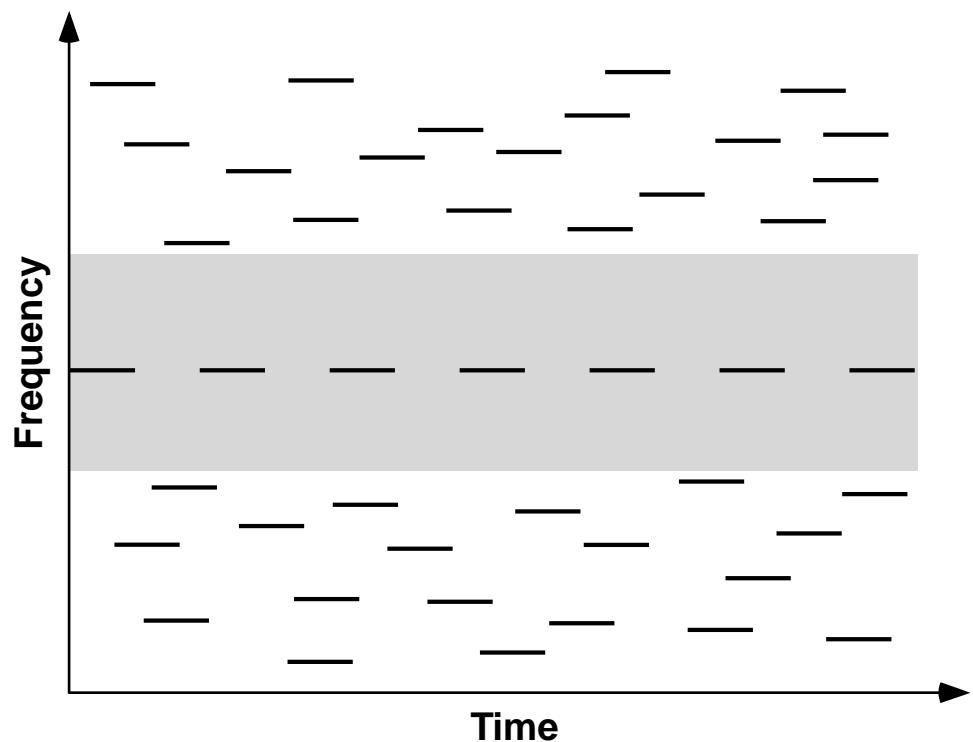
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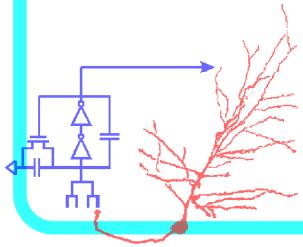
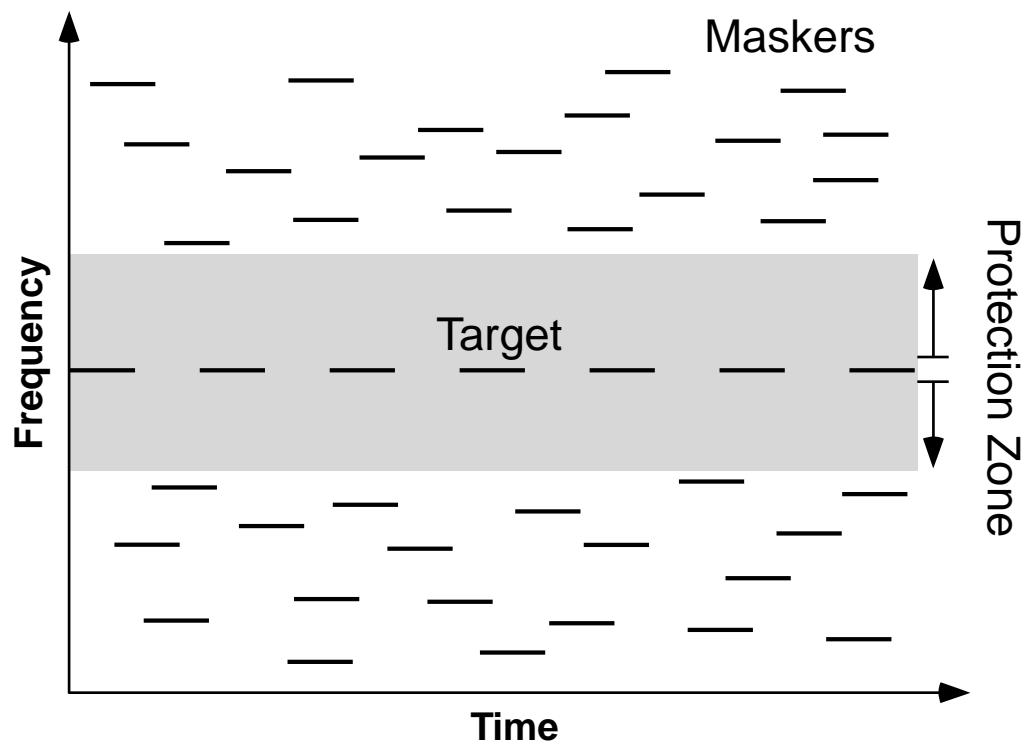
Foreground & Background



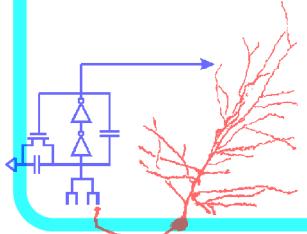
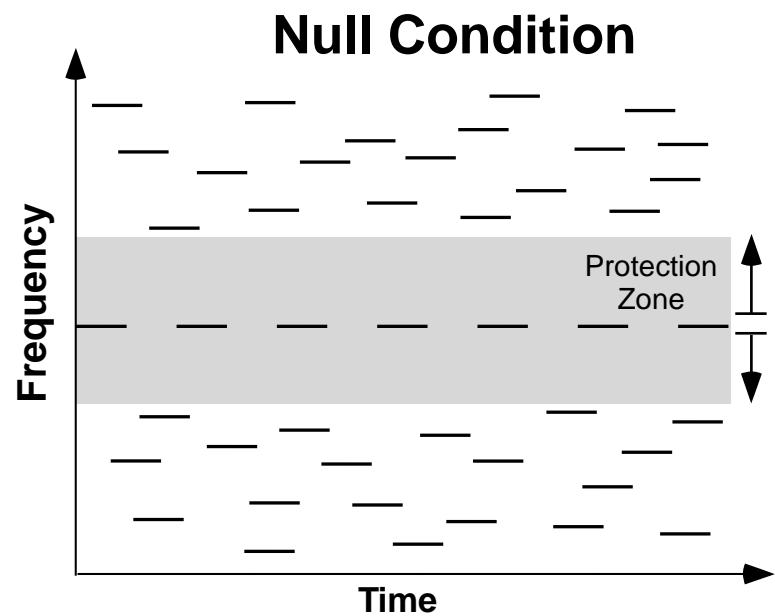
Foreground & Background



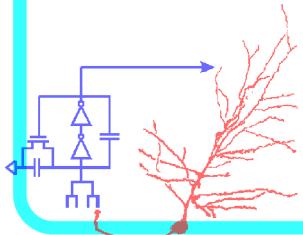
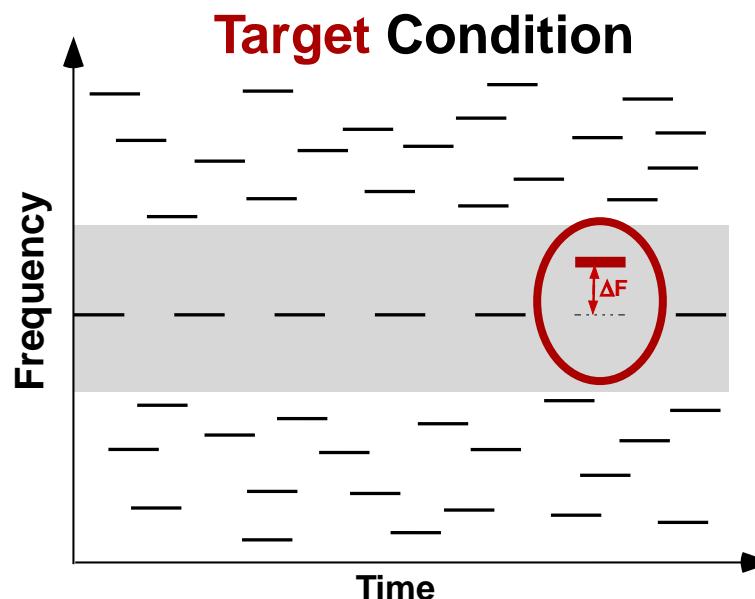
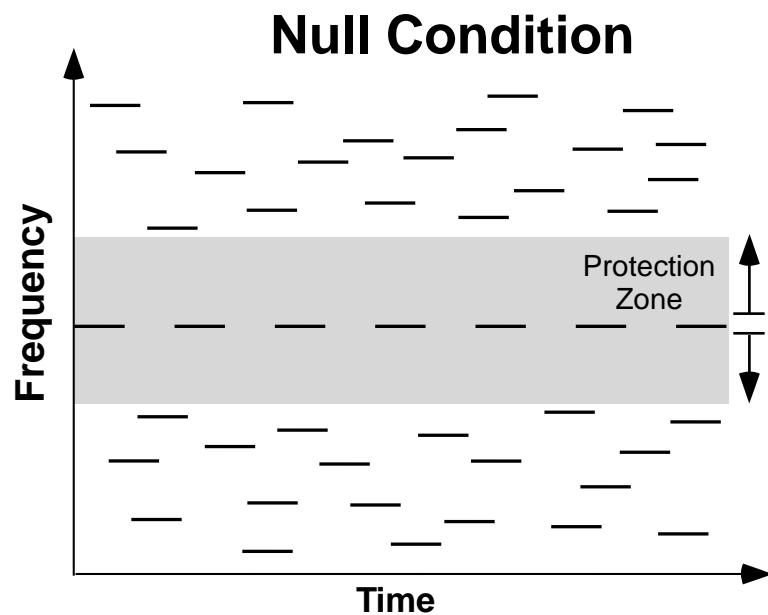
Foreground & Background



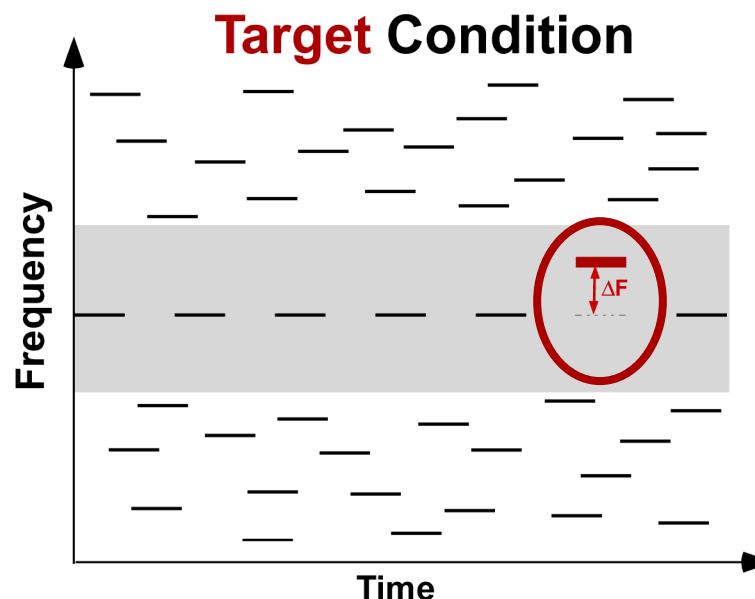
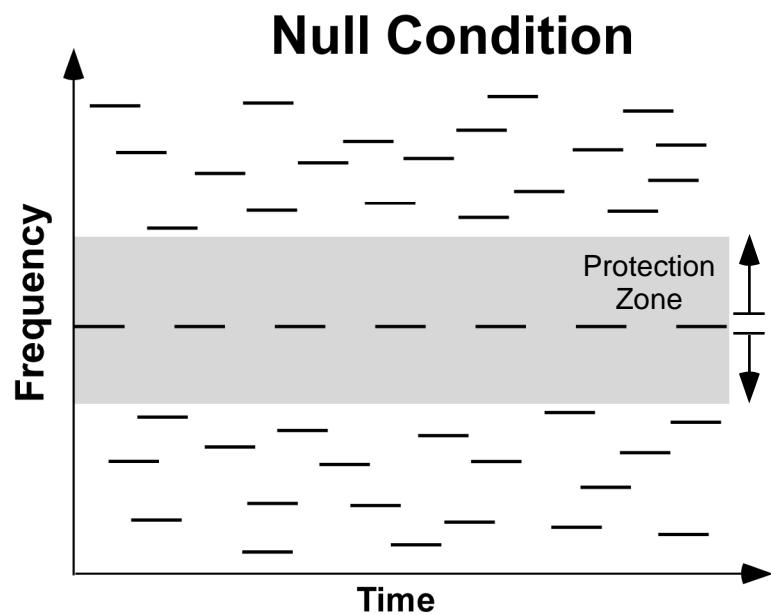
Experimental Paradigm



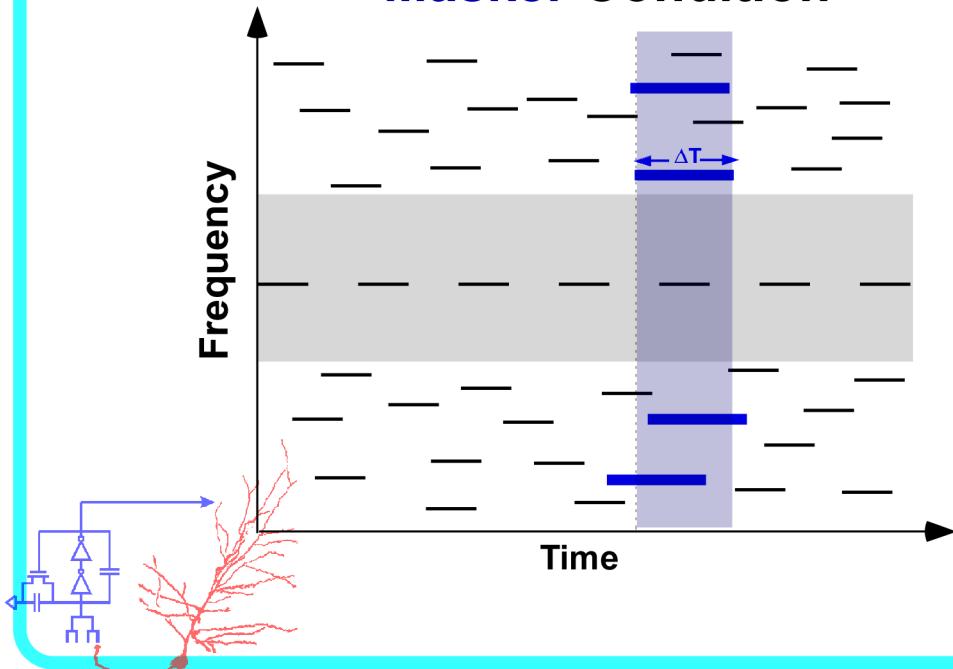
Experimental Paradigm



Experimental Paradigm

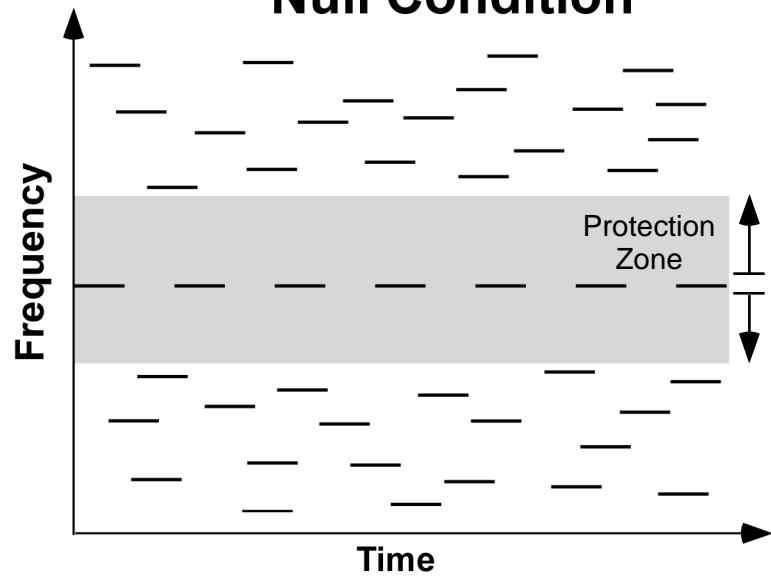


Masker Condition

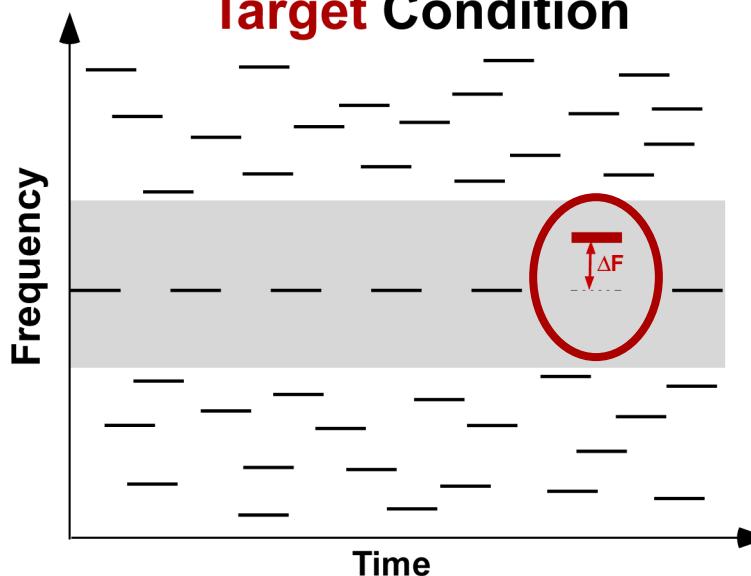


Experimental Paradigm

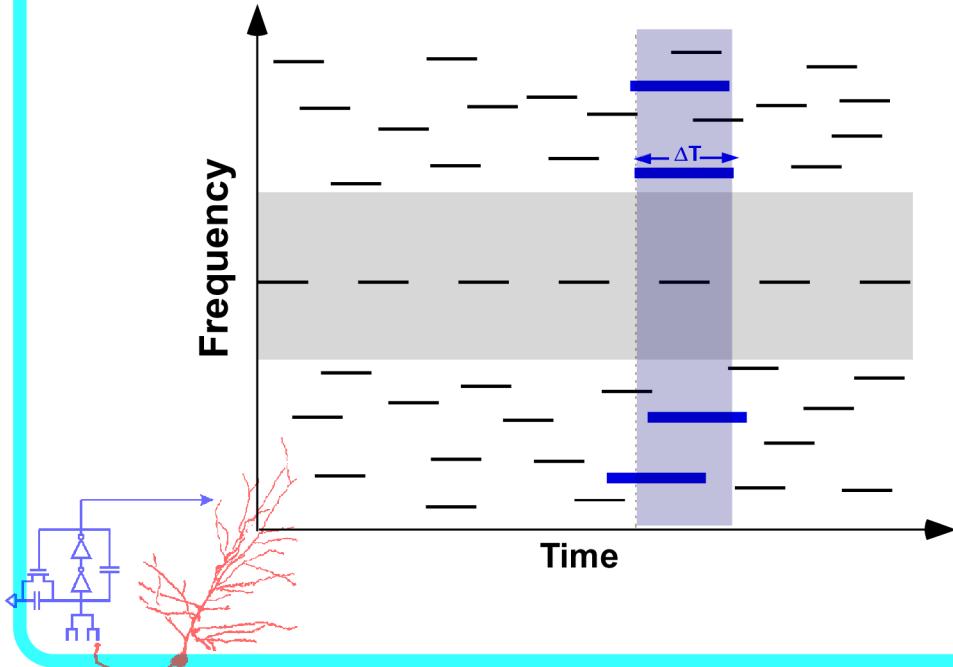
Null Condition



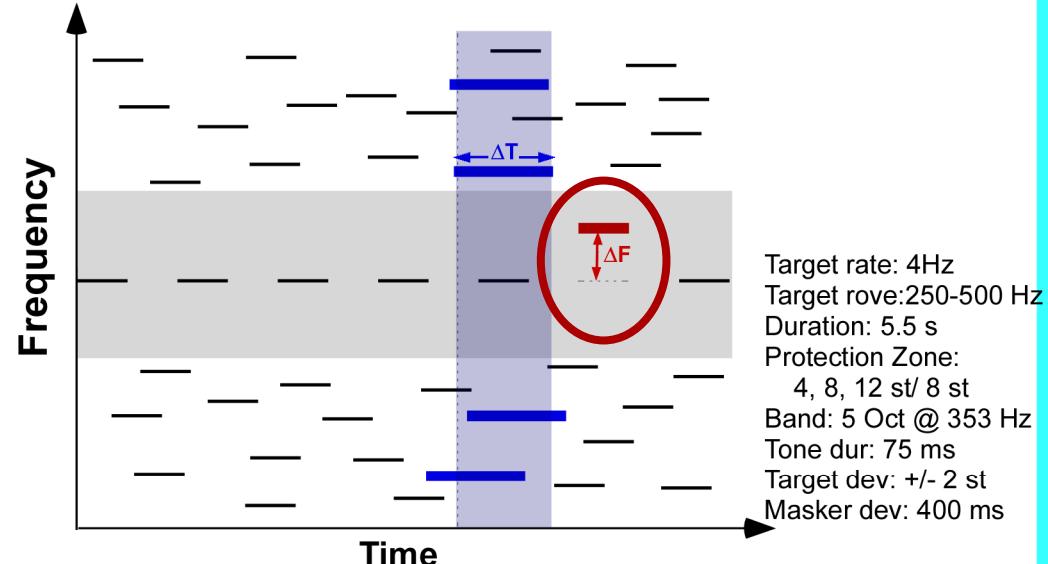
Target Condition



Masker Condition

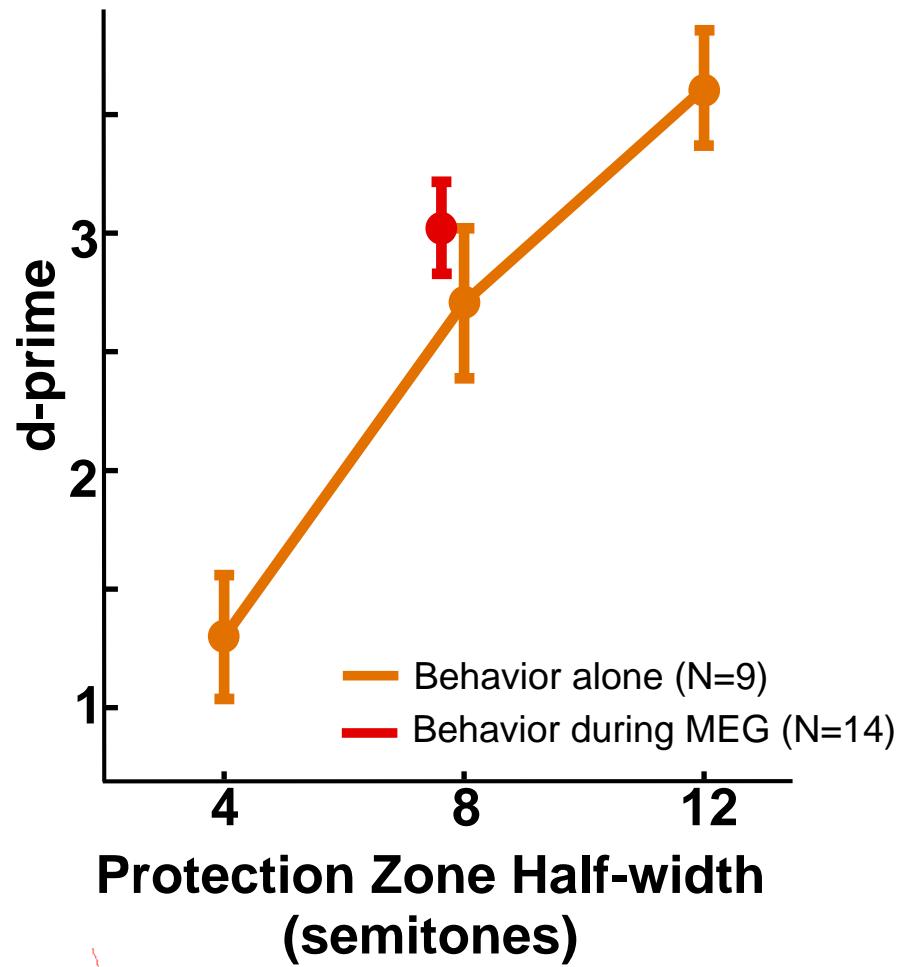


Target & Masker Condition

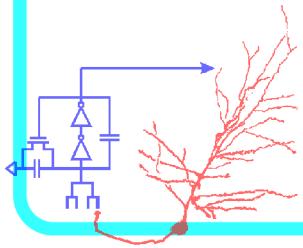
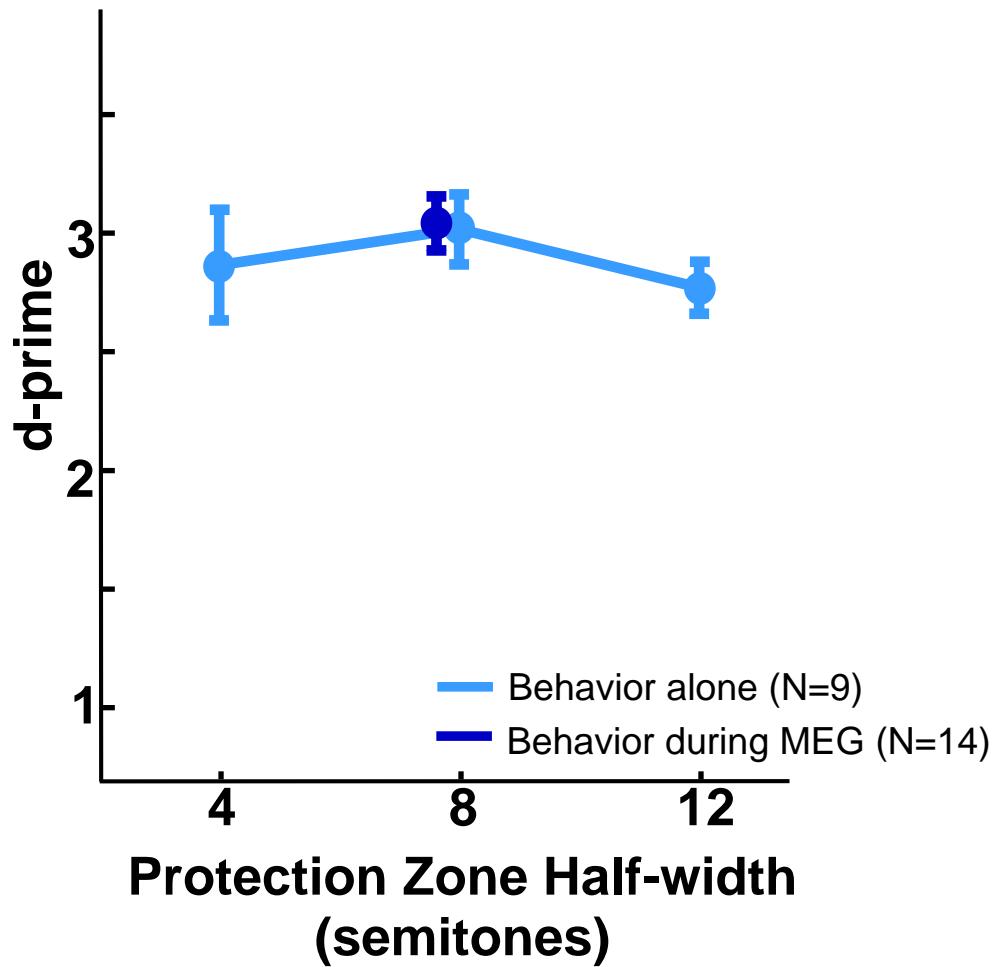


Behavior

**Behavioral Performance
for Target Task**

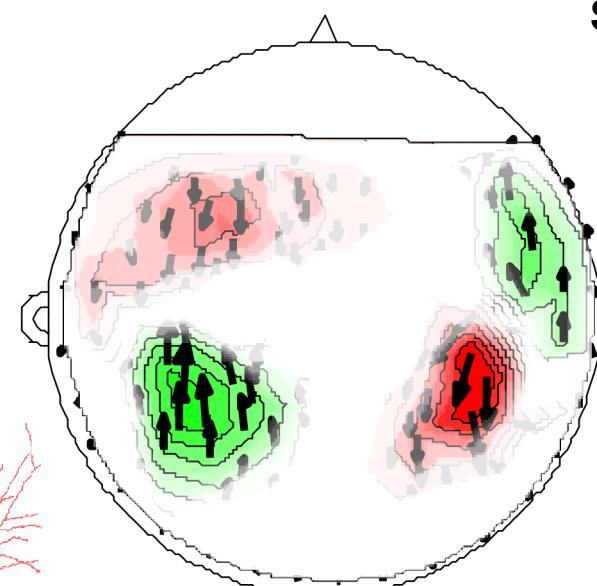
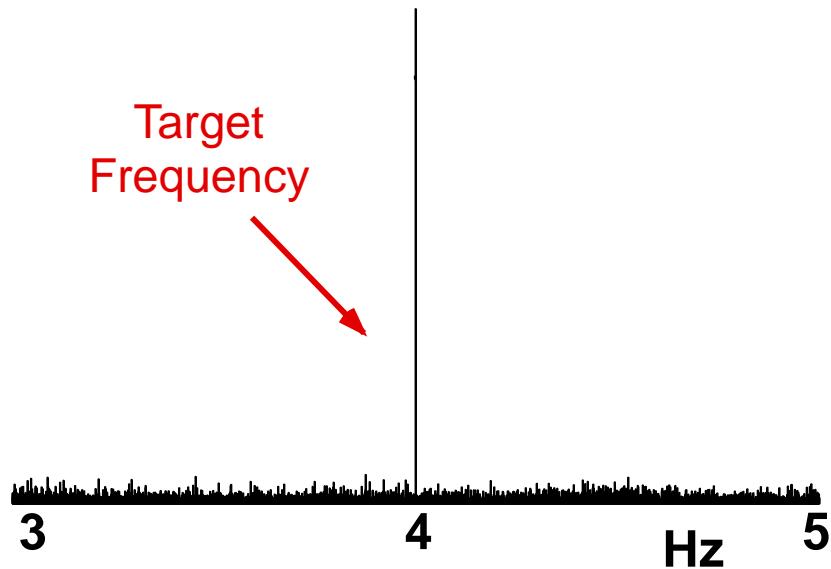


**Behavioral Performance
for Masker Task**



Neural Response to Target

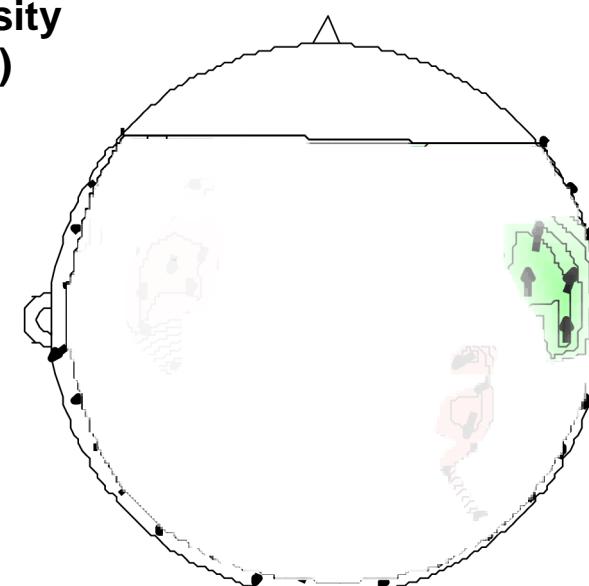
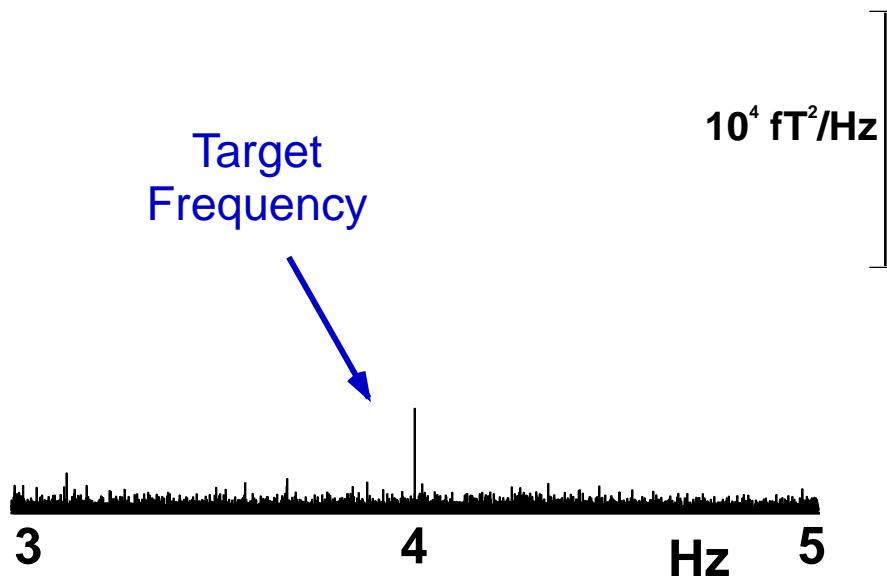
Neural Response to Target
Target Task



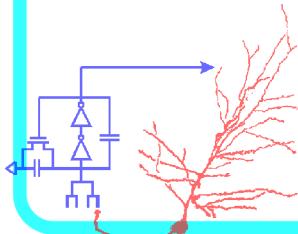
Spectral Power Density
(20 best channels)

Whole Head
Neural Response
to Target

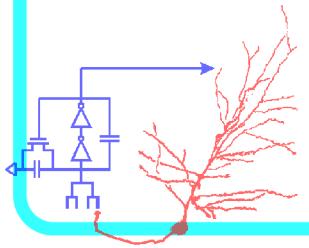
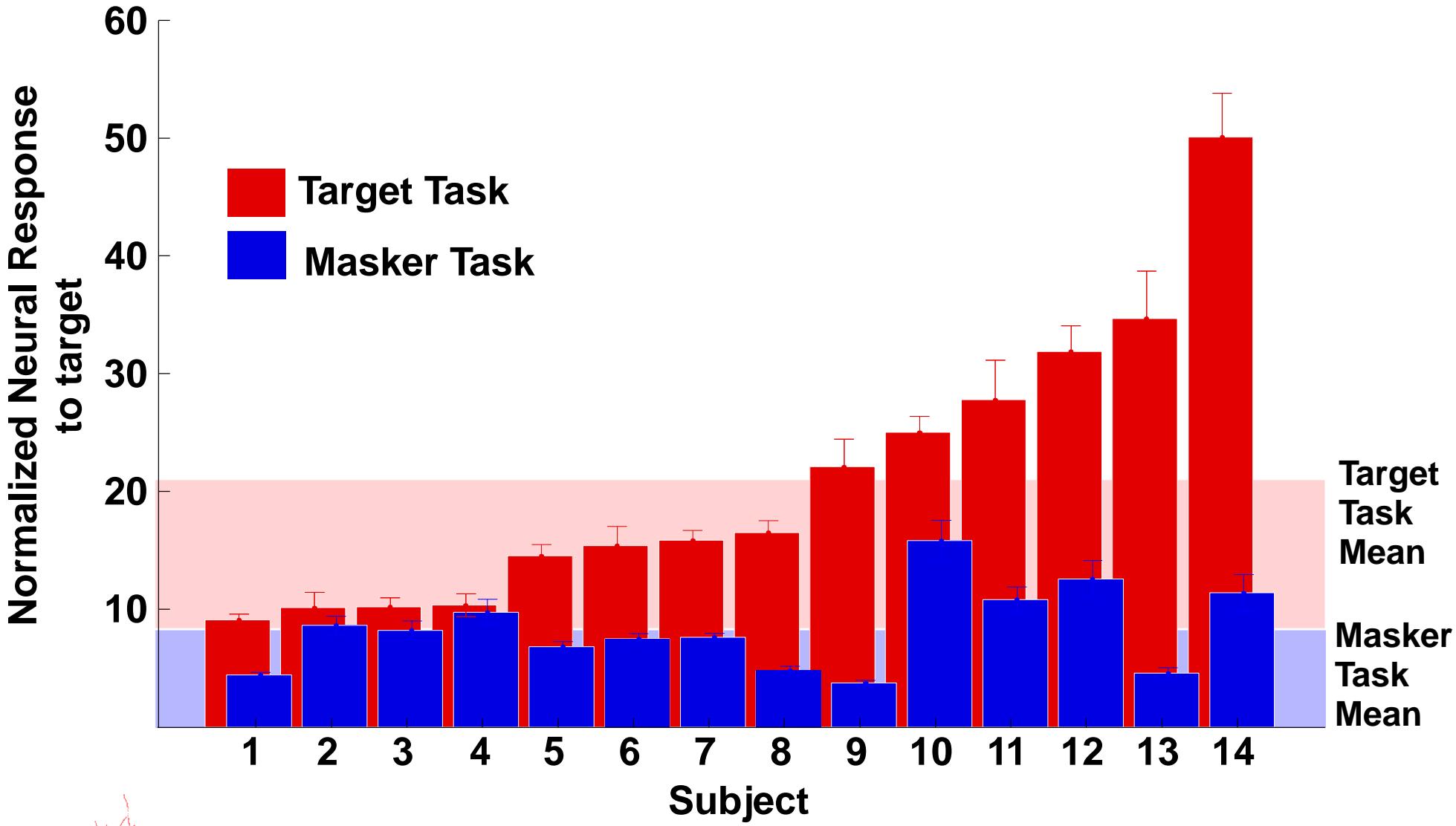
Neural Response to Target
Masker Task



+5
Field Strength
($\times 10^3 \text{ fT}/\text{Hz}$)
-5

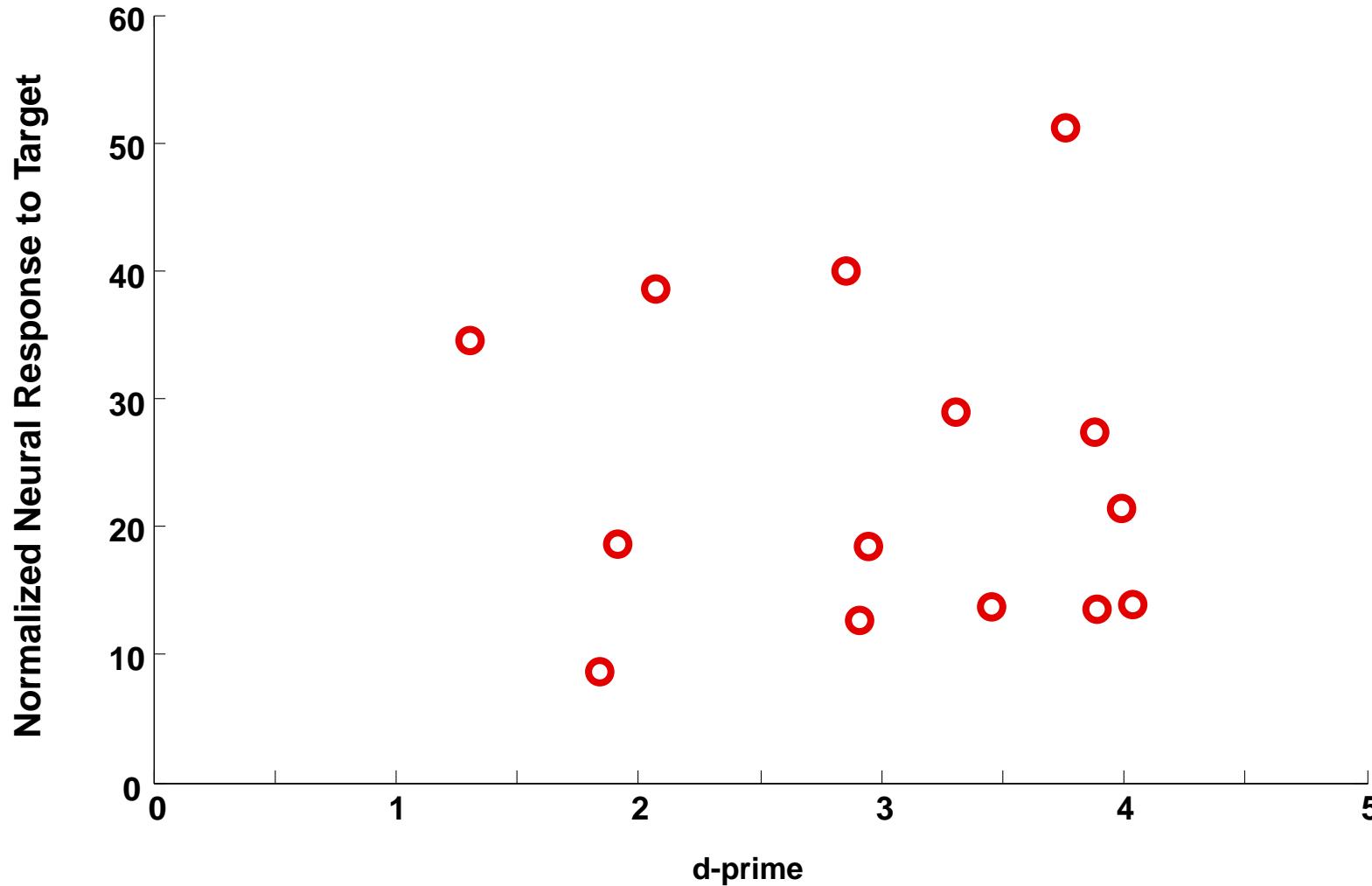


Neural Response to Target by Subject



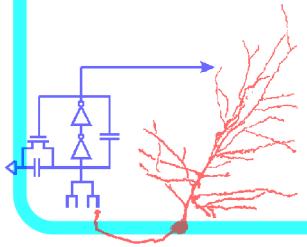
Neural Response to Target vs. Behavior

Normalized Neural Response to Target



Behavior (Target)

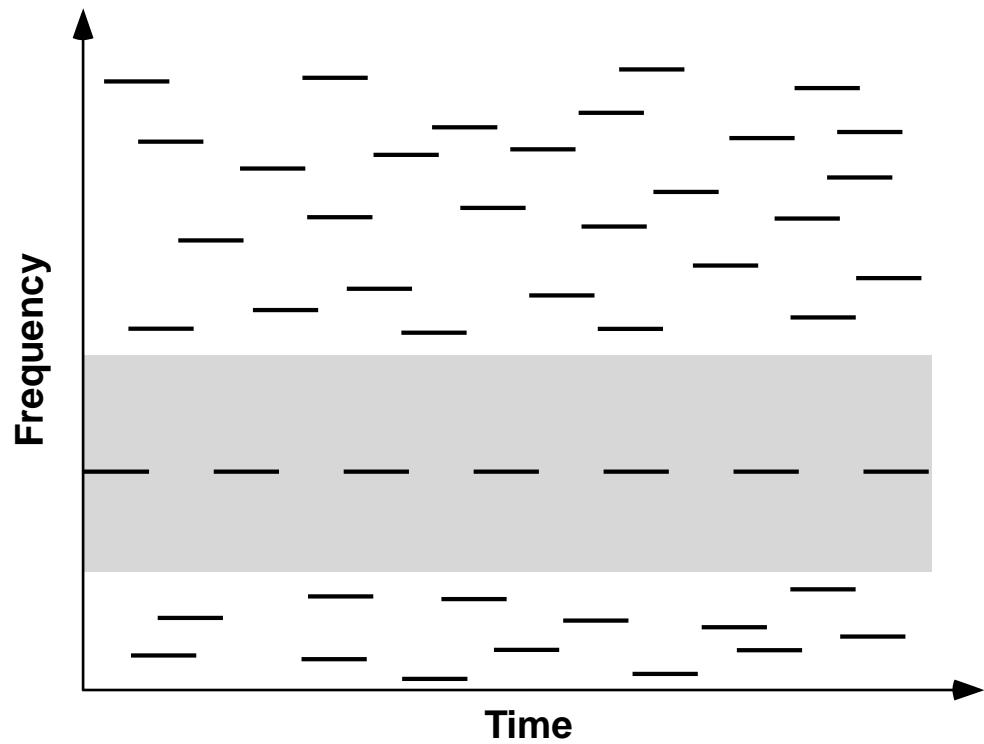
Target Task



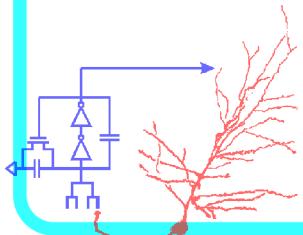
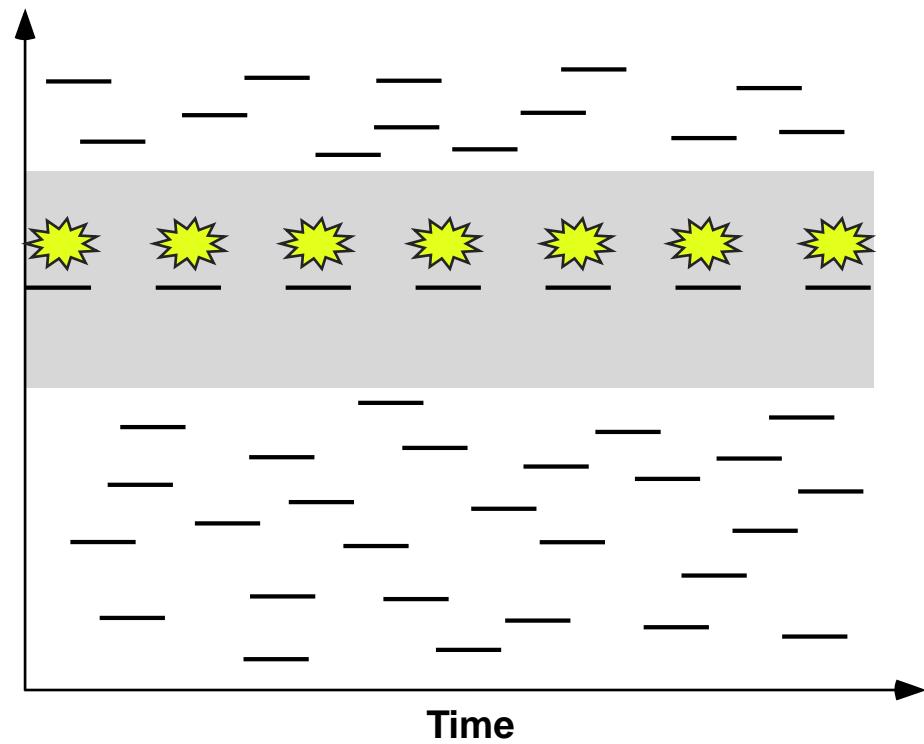
Effect of Target Frequency

Auditory Pop-out

Low-frequency Target



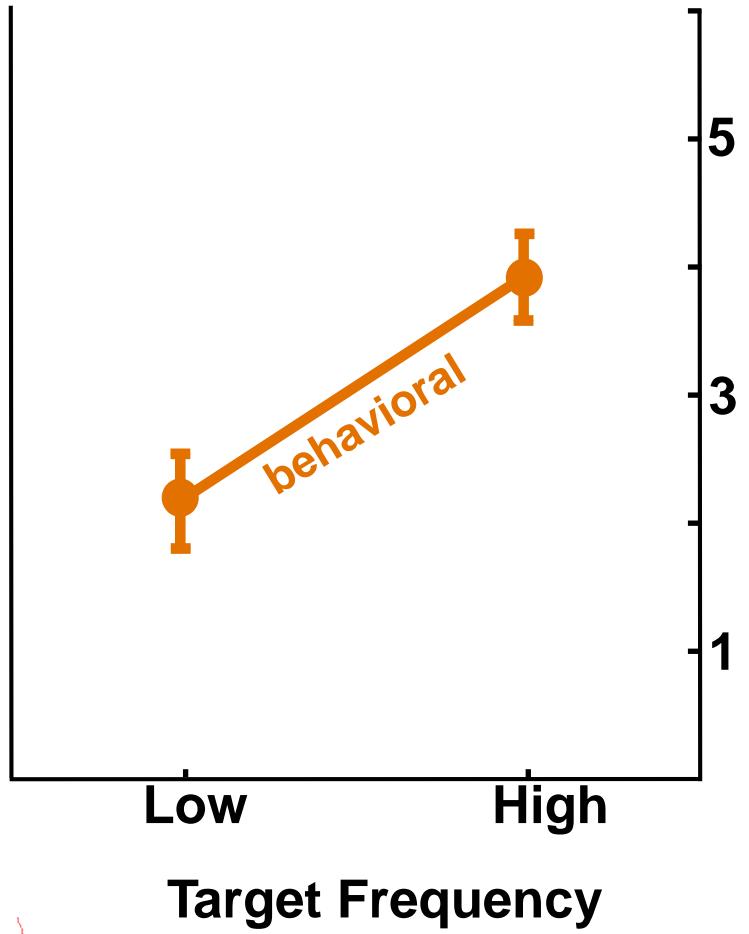
High-frequency Target



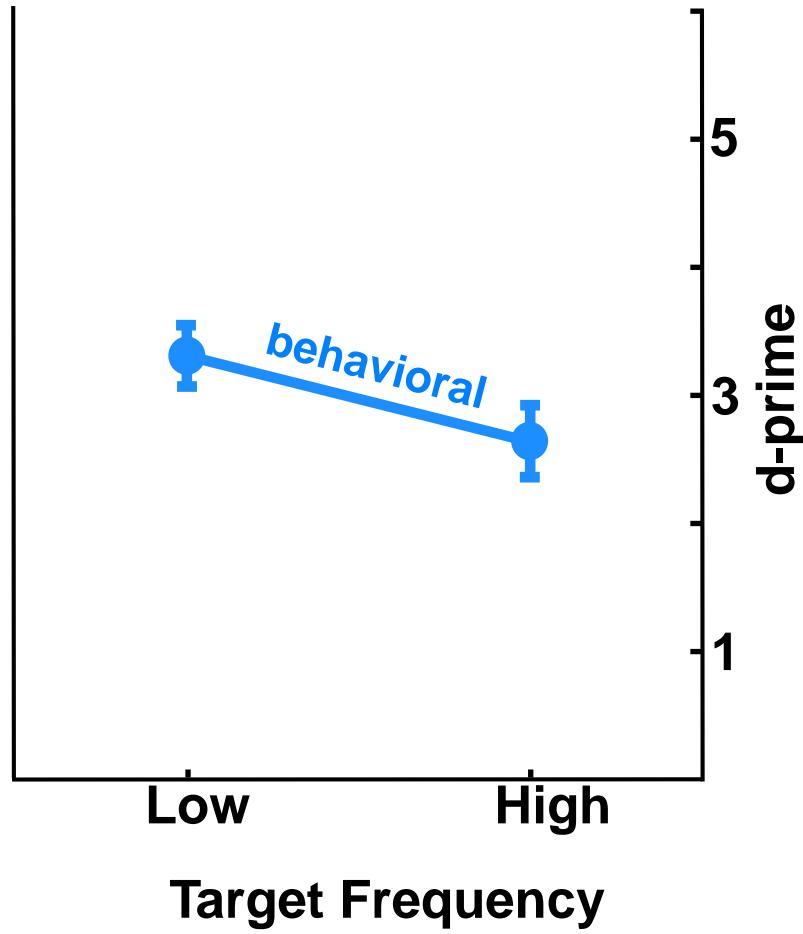
Effect of Target Frequency

Auditory Pop-out

Target Task

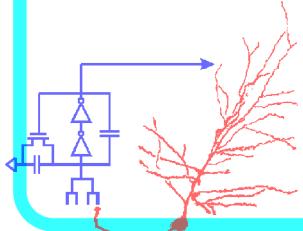


Masker Task



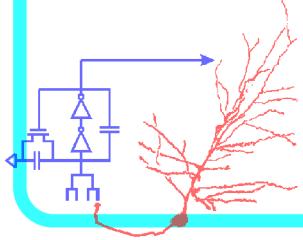
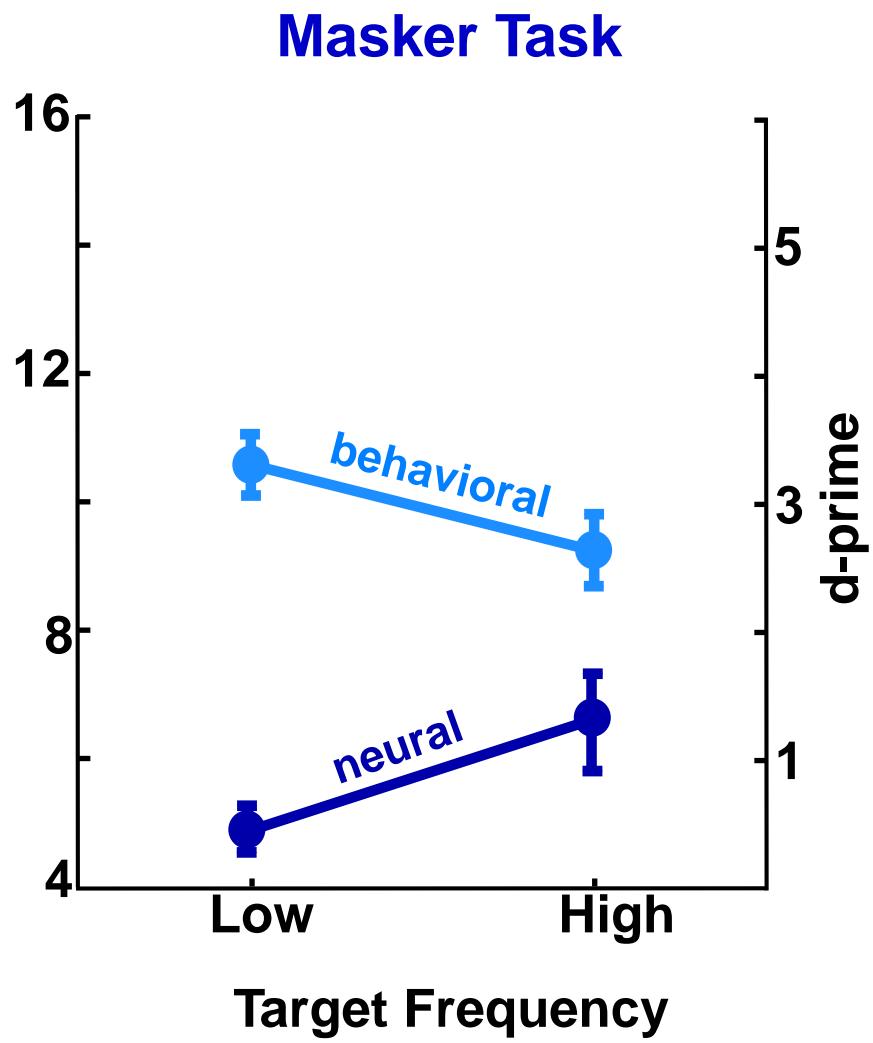
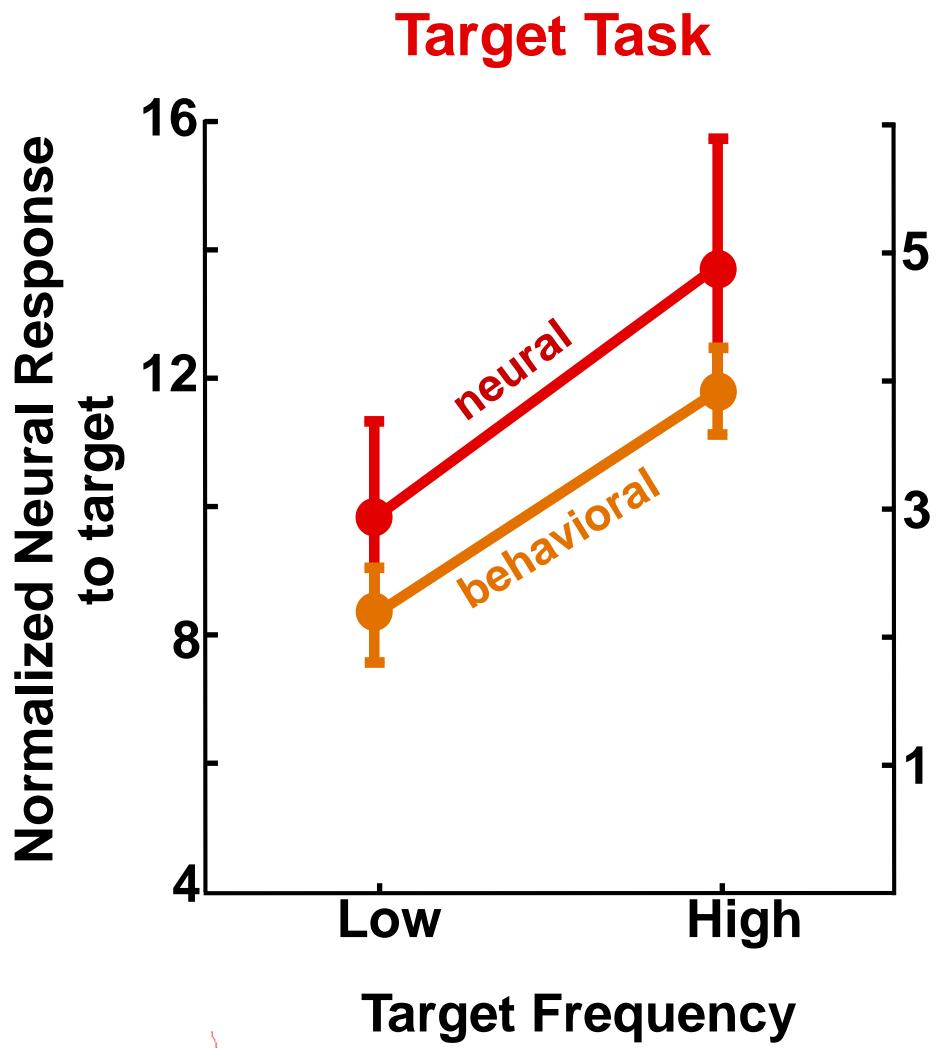
— Behavior from MEG (N=14)

— Behavior from MEG (N=14)

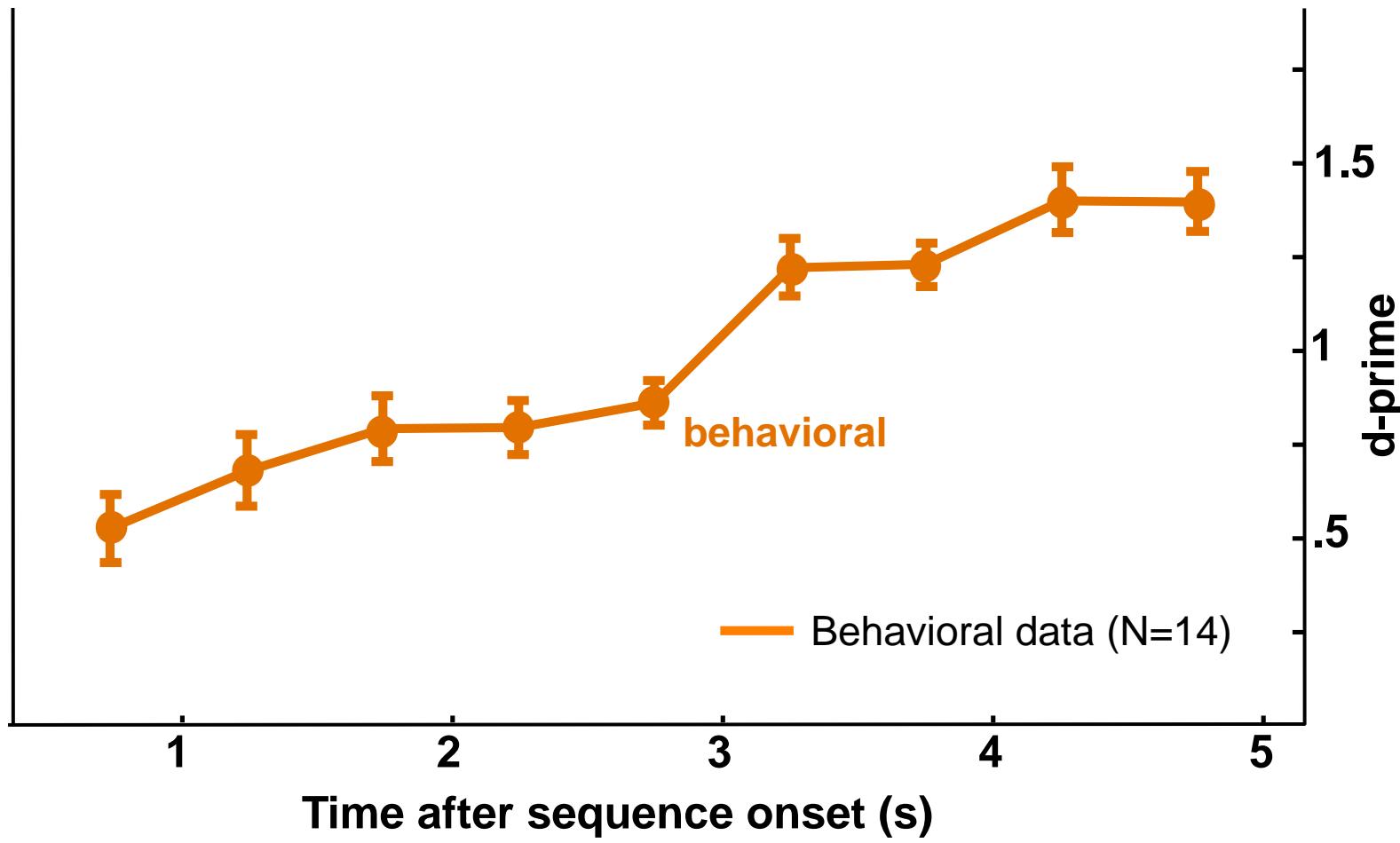


Effect of Target Frequency

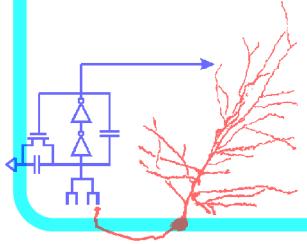
Auditory Pop-out



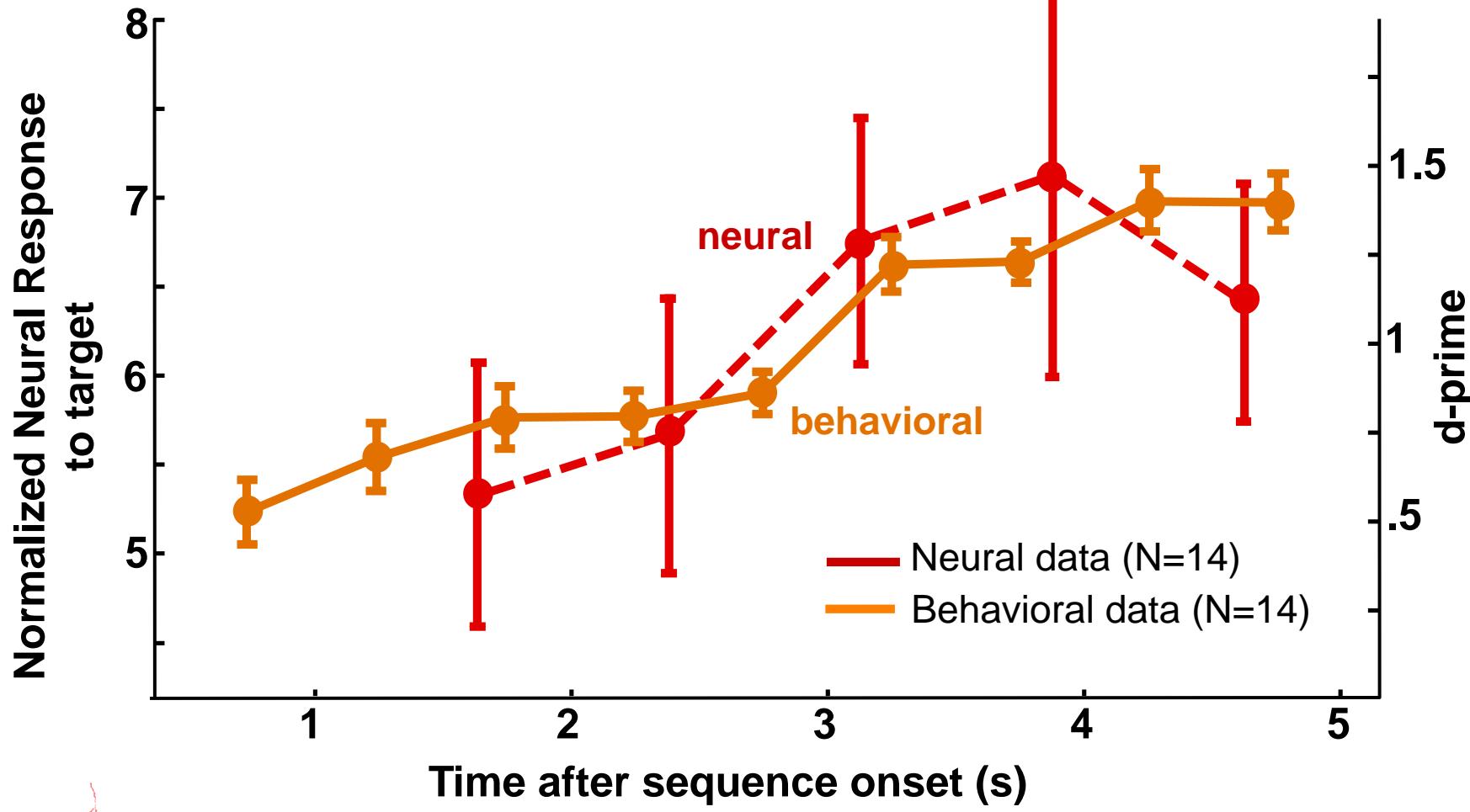
Behavioral & Neural Build-ups



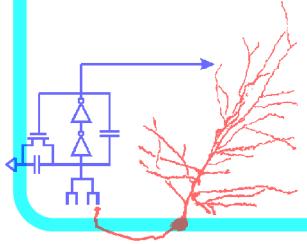
Target Task



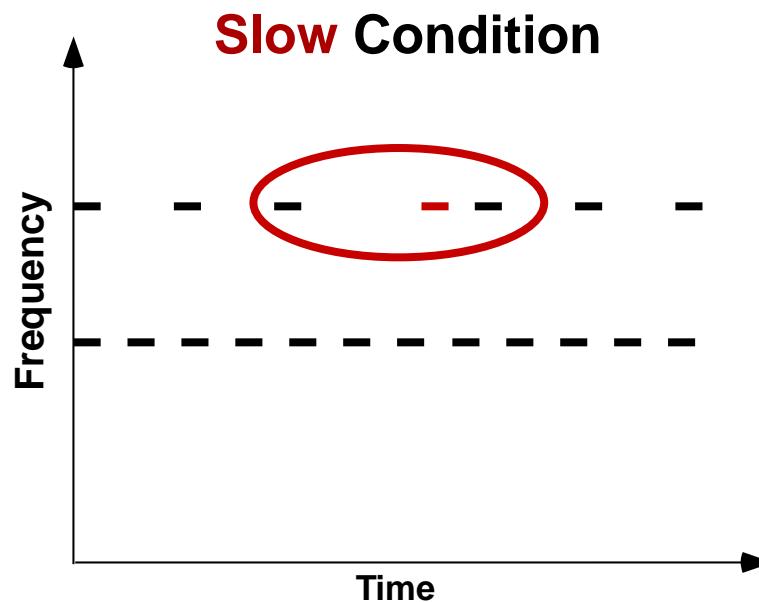
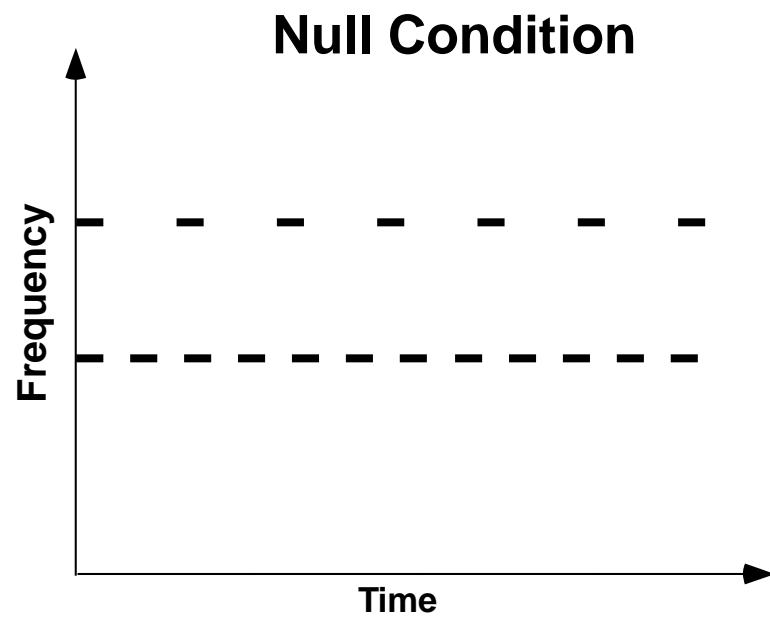
Behavioral & Neural Build-ups



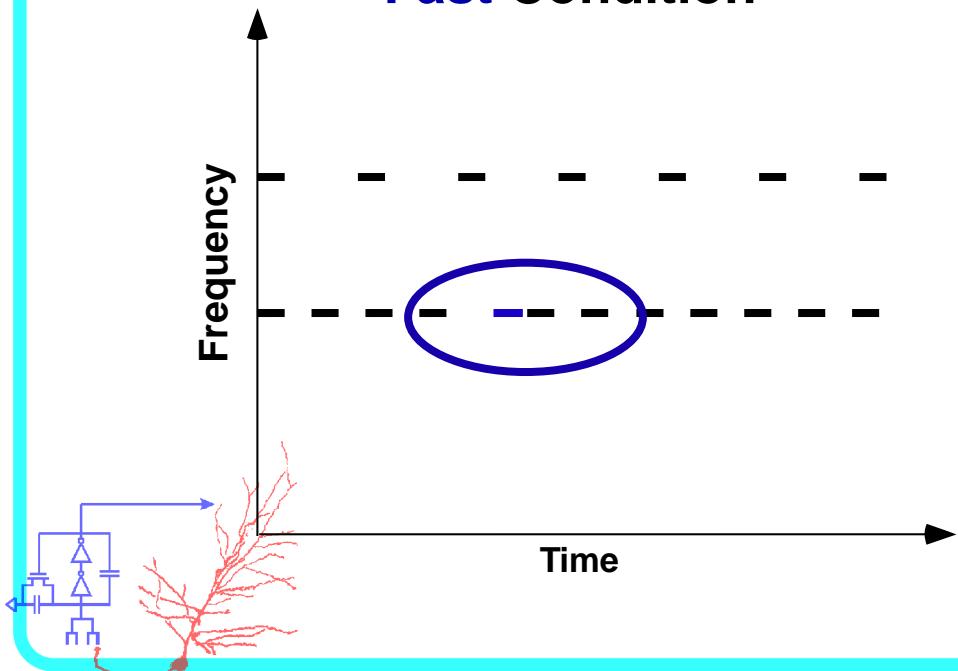
Target Task



Follow-up Study (in progress)



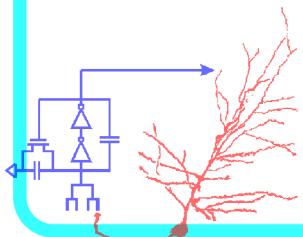
Fast Condition



Target rates: 4Hz, 7 Hz
Target rove: 250-500 Hz
Duration: 5.25 s, 6.25 s, 7.25 s
Frequency Separation: +/- 8 st
Tone dur: 75 ms
Deviant Jitter: 40 ms, 70 ms

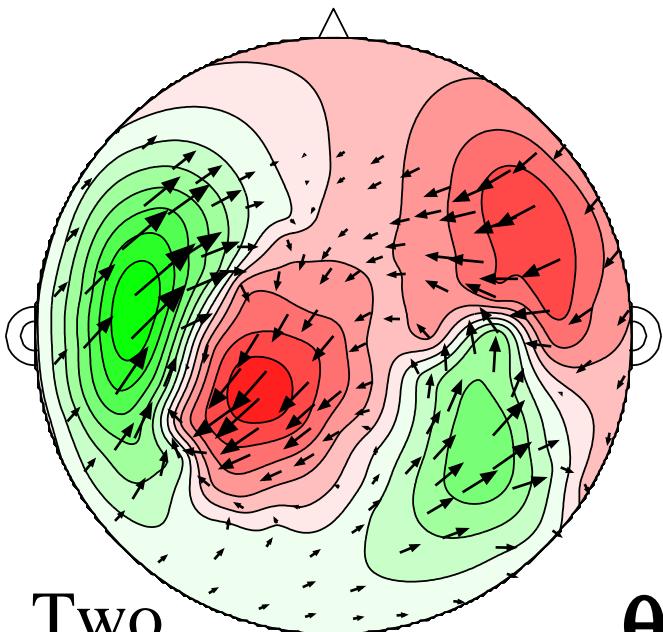
Summary

- Strong Neural Response to Target (despite Maskers)
 - + Acquired non-invasively, from human subjects
- Attention strongly modulates Neural Response
- Change in Behavior correlates with Change in Neural Response
 - + Auditory Pop-out
 - Target Pop-out correlates with Neural Response
 - Target Pop-out interferes with Masker Task
 - + Similar buildup for Behavioral & Neural Response



Thank You

Complex Equivalent-Current Dipoles



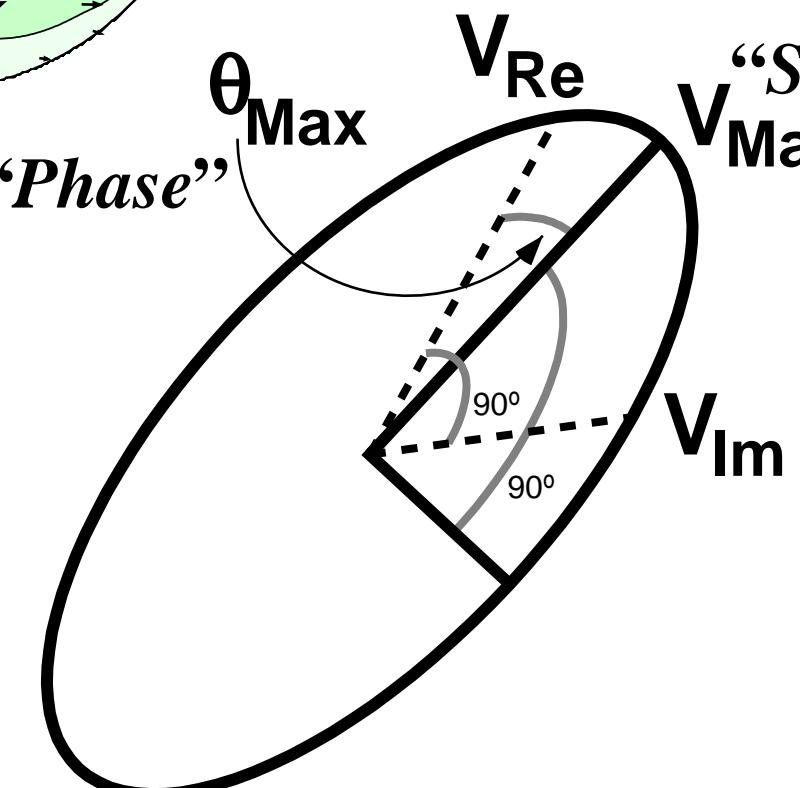
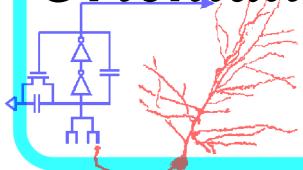
Two
Dipole
Fit

“Phase” θ_{Max} \vec{V}_{Re} \vec{V}_{Max} “Strength”

“Sharpness”

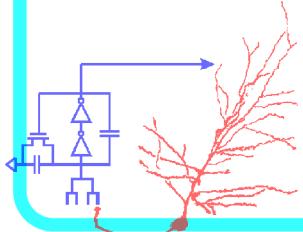
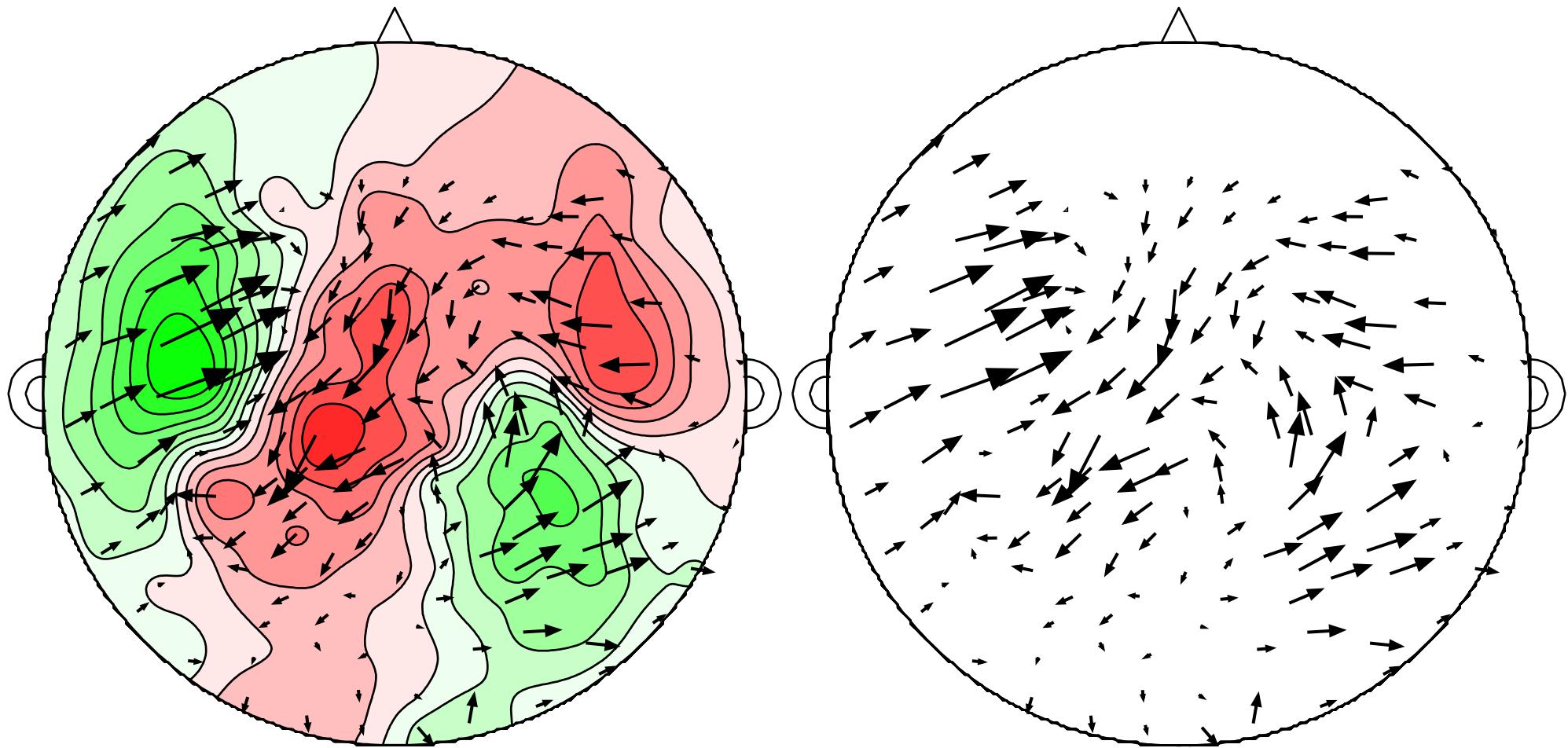
$$\eta = \frac{|\vec{V}_{\text{Min}}|}{|\vec{V}_{\text{Max}}|}$$
$$0 < \eta < 1$$

$\hat{\vec{V}}_{\text{Max}}, \hat{\vec{V}}_{\text{Min}}$
Orientations

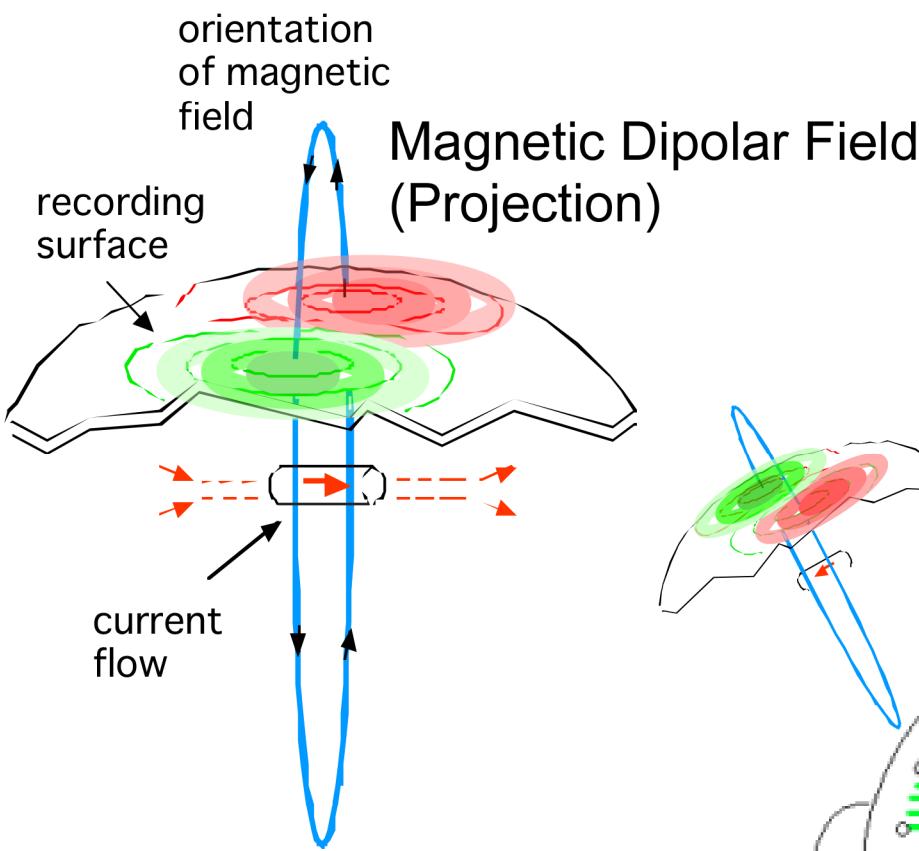


Physiologically Simple
Current Sources: $\eta = 0$

Complex Magnetic Field



MEG Measures Neural Currents



- MEG = Magnetoencephalography
- Direct electrophysiological measurement
 - not hemodynamic
 - real-time
- No unique solution for distributed source

